DOCUMENT RESUME

ED 287 436 HE 020 910

AUTHOR	Kozma, Robert B.; Bangert-Drowns, Robert L.
TITLE	Design in Context: A Conceptual Framework for the Study of Computer Software in Higher Education.
INSTITUTION	National Center for Research to Improve Postsecondary Teaching and Learning, Ann Arbor, MI.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE	Oct 87
GRANT	OERI-86-0010
NOTE	78p.; From the NCRIPTAL Program on Learning, Teaching, and Technology.
AVAILABLE FROM	NCRIPTAL, Suite 2400 School of Education Building, The University of Michigan, Ann Arbor, MI 48109-2748 (Technical Report No. 87-F-001.0, $10.00).
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	*Classification; College Instruction; College Students; *Computer Assisted Instruction; Educational Research; Educational Technology; Higher Education; *Learning Motivation; Learning Processes; *Microcomputers; Programed Instruction; *Research Design; *Research Needs; Research Projects; Simulation

ABSTRACT

The conceptual groundwork needed to examine the impact of technology, primarily microcomputers, on student learning is presented. Medium, method, and context are tied with a science of design. In section I, research on technology in higher education is reviewed, medium and method are defined, and interaction with context is discussed. Taxonomies on instructional contexts and design are considered in section II, including the purpose of a taxonomy, instructional contexts (learner aptitudes, learning tasks, and situations), and instructional designs. In the final section the taxonomy is used to identify and describe classes (tutorials, guided simulations, exploratory environments, cognitive tools, graphics, motivation, user interface, and feedback) of computer applications, or designs, and the instructional situations for which each might be most effectively used. A research agenda is provided from which NCRIPTAL (National Center for Research to Improve Postsecondary Teaching and Learning) researchers will work. One hunred and fifty references are included. (LB)

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Design in Context

A Conceptual Framework for the Study of Computer Software in Higher Education

October 1987

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Design in Context

A Conceptual Framework for the Study of Computer Software in Higher Education

October 1987

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The project presented, or reported herein, was performed pursuant to a grant from the Office of Educational Research and Improvement/Department of Education (OERI/ED). However, the opinions expressed herein do not necessarily reflect the position or policy of the OERI/ED and no official endorsement by the OERI/ED should be inferred.

Contents

Introduction 1

I. Learning, Teaching, and Technology 3

1. Research on Technology in Higher Education 5
    - Early Reviews 5
    - Recent Reviews 5
    - Clark's Critique: Sources of Overstatement 6
    - Sources of Understatement 6
2. Treatment Definition 7
    - Medium Defined 7
    - Method Defined 8
    - Medium and Method 9
3. Interaction with Context 11
    - Context 11
    - Designing for Context 12

II. Taxonomies of Instructional Contexts and Design 15

4. Purpose of a Taxonomy 17
    - Utility of Taxonomies 17
    - Structure of Taxonomies 18
    - Implications for a Taxonomy of Instructional Treatments 18
5. Instructional Contexts 21
    - Learner Aptitudes 21
    - Learning Tasks 25
    - Situations 30
6. Instructional Designs 33
    - Media Attributes 33
    - Methods 36

III. A Taxonomy of Educational Computing Designs 43

7. Computer Capabilities 45
8. Categories of Instructional Computer Software Designs 49
    - Tutorials 49
    - Guided Simulations 52
    - Exploratory Environments 55
    - Cognitive Tools 56
    - Graphics 58
    - Motivation 61
    - User Interface 62
    - Feedback 63
9. Research Agenda 67
    - Methodological Concerns 68

References 71

Figures

1. The relationship between medium and method 9
2. Design as local theory 13
3. Parallels between learner aptitudes and learning tasks 31
4. Parallel between learner aptitudes, tasks, and media control capabilities 36
5. An example of a tutorial from a chemistry program 51
6. An example of a guided simulation 53
7. An example of an exploratory environment 56
8. An example of a cognitive tool 58
9. An example of a cognitive tool 59
10. An example of visual representation 60
11. An example of a symbol system transformation 61
12. An example of a user interface with low cognitive demands 64

Note on the October 1987 Version

We identify this document as a "version" to convey the idea that our thinking on the topics addressed here is still in the formative stage. We have received many good suggestions from those that have read this (especially our formative advisor, Richard Clark), and they raise important issues that we have not yet fully incorporated into our thinking. We view this as an interim document that will guide our initial efforts. As we learn more from our research and experience we plan to return to this document to produce a subsequent version. Please bear this in mind.

R. B. K.
October 16, 1987

Introduction

A fundamental transformation in the structure of American society has begun. The future of our culture and economy is no longer in industrial production but instead in the organization and transmission of information. Early forms of information technologies have already proved their potential. Such ubiquitous instruments as the telephone, radio, and television have made their indelible mark on our culture, changing the ways we spend our days and view the world. Improvements in these technologies, such as cable television, satellite communication, laser-recorded videodiscs, and fiber-optic voice transmission, promise to extend this impact.

But without a doubt the most important development in information technology has been the computer, what Nobel Laureate Herbert Simon refers to as "a once in several centuries invention." This machine has brought its extensive capabilities to our schools, offices, labs, and countertops to help us make decisions and improve our productivity.

Perhaps it is inevitable that such a powerful tool for storing, processing, and managing information would affect those social structures most responsible for the preservation and communication of knowledge—our institutions of higher education. There have been computers on college campuses as long as there have been computers, but the increasing power, accessibility, interactivity, affordability, and interconnectedness of microcomputers may change higher education in profound ways. The structure of these organizations may be altered as resources are linked across institutional boundaries and the locus of learning moves from the classroom to the library, office, or home. The curriculum may change as the study of computers spreads from the computer science department and the professional schools into the natural and social sciences and even the humanities. The role of the faculty may evolve from that of the primary deliverer of information to that of resource manager, knowledge engineer, or designer. Finally, computers may change the ways students study and learn and, perhaps, even the way they think.

University administrators and faculty members have reason to be skeptical in the face of such projections (Bok, 1985). Certainly prophecies about other instructional inventions, such as teaching machines, have never been fulfilled, and even such socially successful technologies as telephones and television have had only limited effects on schooling. The impact of computers, however, is already being felt on campus.

In a recent survey sponsored by the Corporation for Public Broadcasting (Riccobono, 1986), 2,429 colleges and universities (a 86% response rate) responded to questions about their use and plans for computers and other instructional technologies. Of those responding, 89% had more than 10 microcomputers and 38% had more than 50. In public four-year institutions, 69% had more than 50 and 18% had more than 250. Currently 27% of the institutions require computer literacy for at least some of their students.

Although there are already many computers on college campuses, the growth appears to have just begun. Currently, seven percent require all of their undergraduates or those in certain fields to own their own computers, but an additional nine percent are considering such an ownership requirement for the future. Over the next two years, seventy-seven percent of the institutions plan on spending at least as much on equipment as they have over the last two years, while fifty-seven percent said they planned on spending more. The growth in software is expected to be even greater, with sixty-five percent saying they plan on spending more on software over the next two years than they have during the last two.

To manage these changes, policy makers (Baldrich, Roberts, & Weiner, 1984) are recommending the creation of centralized administrative positions (frequently referred to as "computer czars") with large budgets and considerable power over computer resources and policies. Many institutions are already following this course (Turner, 1984).

Though some change seems inevitable, the question remains: What will all this amount to? The answer to this question may well depend on our understanding of the capabilities of this machine and the functions it can be made to serve. If computers and other technologies are to be effectively used on campus, the study and evaluation of technology in higher education is necessary. The import and imminence of these changes make the need for research urgent.

The National Center for Research to Improve Postsecondary Teaching and Learning (NCRIPTAL) has identified educational technology as one of its five research foci. Over the next four years, the Program on Learning, Teaching, and Technology, in collaboration with other NCRIPTAL programs, will examine the impact of technology on the higher education organization, the curriculum, the faculty, and, most importantly, the students.

This report presents the conceptual groundwork needed to examine the impact of technology, primarily microcomputers, on student learning. It ties the study of medium, method, and context together with a science of design. It examines a taxonomy of contextual variables for implications in the use of computer software. The report also presents a taxonomy of medium and method attributes that can be used to describe the instructional applications of computers (and instructional treatments, more generally). These descriptors functionally correspond to other elements in the instructional context: the learners, tasks, and situations in higher education. By identifying constructs and variables and the hypotheses that relate them, the taxonomy is intended to serve as a foundation for our own work and, we hope, that of other researchers and practitioners. In the final section of this report, we use the taxonomy to identify and describe four classes of computer applications, or designs, and the instructional situations for which each might be most effectively used.

I. Learning, Teaching, and Technology

Determining how technology can effectively contribute to the improvement of college teaching and learning is not easy. The outcomes of a college education depend on a complex mix of variables including student preparation, motivation, and ability; faculty knowledge and teaching skill; and the curriculum. Attempting to attribute results to any one source is difficult, even naive. On the other hand, it makes sense for faculty members to ask if technology can be effectively used in their courses, or for developers to ask how they can design software to be more effective. Correspondingly, it makes sense for researchers to search for answers to such questions.

1. Research on Technology in Higher Education

Early Reviews

Historically, research on the impact of technology on learning has progressed in waves corresponding to the introduction of new technologies. Each wave has compared the latest invention to some previous one (Saettler, 1968), with accumulated studies culminating in a summary judgment about the value of the medium. A review of the comparative research would count up those studies that favored a new technology and balance them against those that favored traditional instruction or showed no differences at all. Examples of such reviews include those by Levie and Dickie (1973), Jamison, Suppes, and Wells (1974), McKeachie (1974, 1975; McKeachie & Kulik, 1975), Berliner and Gage (1976), and Schramm (1972). A typical conclusion of these reviews is that for most tests of achievement, one medium is about as good as another.

For example, Jamison et al. (1974) examined the research on the effectiveness of traditional instruction (TI), instructional television (ITV), programmed instruction (PI), instructional radio (IR), and computer-assisted instruction (CAI). The studies compared each of the new technologies to either traditional instruction or to another technology. Consistent significant differences were not found. A sample of summary statements are:

> These evaluations indicate that IR (supplemented with appropriate printed material) can be used to teach most subjects as effectively as a live classroom instructor or ITV (pp. 33-34).
>
> ... it is reasonable to conclude that PI is generally as effective as TI... (p. 41)
>
> ITV can teach all grade levels and subject matter about as effectively as TI... (p. 38)

The authors conclude their review by saying that:

> Students learn effectively from all these media, and relatively few studies indicate a significant difference in one medium over another or of one variant of a medium over another. (p. 55)

Such results would hardly foster confidence in the projection of dramatic changes resulting from the introduction of the latest technology.

Recent Reviews

Recent applications of sophisticated, meta-analytic techniques have uncovered significant findings undetected by the earlier, less sensitive box-score summaries. Using this technique, the Kuliks and their colleagues at The University of Michigan have systematically analyzed hundreds of comparative studies and have drawn conclusions more favorable to new technologies. In 101 studies of computer-based education (CBE), for example, they found small but significant results favoring this technology on student achievement and on attitudes toward instruction and computers (Kulik & Kulik, 1985). Students in computer courses scored on an average ten percentile points higher than students in traditional courses. Furthermore, CBE substantially reduced the amount of time needed for instruction. Students in computer courses required only two-thirds as much instructional time as students in regular courses.

The Kuliks also found similar results favoring technology in other meta-analyses. They found small but significant results favoring programmed instruction, with students using this approach averaging ten percentile points higher than students taking traditional instruction (Kulik, Cohen, & Ebeling, 1980) Students using visually-based instructional treatments, such as television and slide-tapes, scored an average of six percentile points higher on achievement tests (Cohen, Ebeling, & Kulik, 1981). Still, as consistently favorable as these results are, they are not of the magnitude that proponents of technology would predict.

Clark's Critique: Sources of Overstatement

Clark (1983, 1984, 1985) has criticized comparative studies of media upon which the Kulik work draws, contending that even these modest results may be overstated. Findings favoring new media may be due more to curriculum reform accompanying the innovation or to a novelty effect than to the technology itself. Clark claims that media and method are confounded in comparative studies and that uncontrolled variables, not the media themselves, account for the results. He contends that technologically-presented material may have been more carefully planned than the conventional presentation. Indeed, the "technology" in the Kulik studies that resulted in the greatest gains was Keller's Personalized System of Instruction (PSI), an approach that emphasizes small steps, mastery, and frequent feedback (Kulik, Kulik, & Cohen, 1980). "High technology," such as television and computers, is not part of this approach. In light of these problems, Clark (1983) concludes his review in consonance with previous commentators: for learning, no one medium has an advantage over another (with the possible exception of its cost-effectiveness of delivery).

Sources of Understatement

There are two types of error that one must be concerned with in any research. One type is a false positive, or source of overstatement of positive effects. This is the type of error that Clark addresses in his critiques. A second type of error is a false negative.

While Clark makes it clear that the mere introduction of a technology will not increase achievement and that instructional method plays a crucial role in the effectiveness of a treatment, there may be ways in which a comparative study actually **understates** the impact of a medium, such as computers. There are at least two factors that can moderate differences in outcomes in this way: the lack of precise treatment definition, and the interaction of treatments with learner and other contextual variables. In the first case, poor treatment definition may result in the inclusion in an analysis of a study that employs a medium but the application of the medium does not use its most distinctive or powerful features. Such an application may minimize the likelihood that the medium would be any more effective than the alternative treatment. The inclusion of such studies in a meta-analysis would reduce the average observed effect of the medium.

In the second case, it may be that the distinctive features of the medium are used but are mismatched with the learner, task, or situation. That is, it may be that a medium, or an instructional treatment more generally, is not the most effective for all situations but is more effective than another **in certain contexts**. The exclusion of contextual variables in a meta-analysis may also reduce the impact of a medium.

2. Treatment Definition

The definition of instructional technology has historically been a problem. For example, in 1968, the Commission on Instructional Technology gave two definitions of "instructional technology." The first definition is "media born of the communications revolution which can be used for instructional purposes..." (Tickton, 1970, p. 7). This is the more common conception of instructional technology as the educational application of television, film, radio, computers, and so forth. The second definition is "a systematic way of designing, carrying out, and evaluating the total process of learning and teaching in terms of specific objectives, based on research in human learning and communication, and employing a combination of human and nonhuman resources to bring about more effective instruction" (p. 7). In this report and our research we will use this second, more comprehensive definition for instructional technology. The first definition will be reserved for instructional media. Thus, instructional technology defines a field that encompasses the process used to design various instructional treatments; this includes the selection and application of instructional media and instructional methods.

Medium Defined

Having selected medium as the term best used to describe computers and other ways of delivering instruction, we still have no means to describe or distinguish various forms of media other than by the superficial differences related to their physical appearance—their hardware devices. Nor does it give us a means for understanding the confounding of medium and method. The "hardware" perspective treats all of the applications of a particular medium as uniform and monolithic; all educational studies that use a television, for example, are grouped together. In reality, applications of a medium vary considerably and some applications may not use the more unique and distinctive features that a medium provides. Thus a "talking head" television presentation may be no more effective than a radio presentation because it makes such minimal use of its capacity to communicate information visually. Such a presentation would not be an appropriate treatment to use in testing the differences between radio and television. The clearest comparative test of two media would involve treatments that appropriately employ the most distinguishing characteristics of each. Ignoring these differences blurs the distinctiveness between media, increases error variance among studies, and reduces the likelihood that any differences in impact would emerge. Thus, media need to be defined in terms of the characteristics or attributes that distinguish between them and that are most likely to influence learning, rather than in terms of their physical hardware.

In this report, media are defined in terms of their functional characteristics, their capabilities to implement certain instructional methods. These capabilities are certainly enabled and constrained by "hardware," but, defining media in these terms, especially as these capabilities correspond to cognitive functioning, is more likely to create distinctions that relate to differences in learning, if differences are to be found.

Salomon (1974, 1979) points out that each medium is composed of a set of elements, attributes, or capabilities and each can be described by a particular profile of these capabilities. Some of the capabilities of a medium may also be those of other media, some not. A medium is distinctive to the extent that its profile or cluster of attributes is unique. Television and film are practically identical in capabilities (even though their hardware differ considerably); television and radio are different in some capabilities (i.e., the capability of television to present visual motion); television and computers are very different in their capabilities. The more differences there are between media in their capabilities (i.e., the fewer their shared attributes) and the more these differences are employed in the design of their applications, the more they can be treated as different in research considerations.

That two media are different in their capabilities is not sufficient support for a claim that one will be any better or worse for learning. These differences must also have implications for the learning process. One way that media differ, according to Salomon (1979), is in the symbol systems they are capable of employing. Symbol systems are the forms in which information is communicated. A symbol system is a set of elements, or symbols, related to each other by syntactic rules or conventions, and correlated in specifiable ways to fields of reference (Salomon, 1979; Goodman, 1976; Gardner, Howard, & Perkins, 1974). Certain media can employ some symbol systems and not others. Radio, for example, can present audio linguistic symbol systems (i.e., spoken words) while television may present pictorial symbol systems as well as both audio and visual linguistic codes. Salomon contends that knowledge presented in different symbol systems may be represented differently in memory and may require different mental skills to process. The use of a particular symbol system is presumed to be effective to the extent that it corresponds to the mental representation of a particular task for a particular learner and to the extent that it facilitates information processing related to it.

We contend that a second way media differ is in their ability to process or manage information (i.e., symbol systems). We call these control capabilities. Information can be retrieved, displayed, received, stored, processed, and managed in various ways. All media can display information in at least one symbol system, some in several. But media vary considerably in how they can process these symbols. Television can present information, for example, but cannot receive it from the learner or evaluate it; computers can. As with symbol systems, different control capabilities may also require, replace, or model different mental skills. The use of a particular control capability is presumed to be effective to the extent that it corresponds to the mental operations required of a particular learner, task, and situation.

Method Defined

Clark (1983) has effectively argued that media alone cannot explain learning; method is critical. Methods are the various strategies that faculty members and instructional designers use to influence student learning. "Direct," "expository," "individualized," "inquiry," "discovery," and "open" have all been used to describe kinds of instructional methods. These are more-or-less articulated, coherent bodies of instructional practice. The terms, however, refer only to behaviors in the classroom, to what the teacher does or allows the students to do. A more useful approach might be to think of instructional methods in terms of their functional relation to learners' cognitions and motivations.

Salomon (1979) and, more recently, Corno and Mandinach (1983) and Corno and Snow (1986) have created categories of instructional methods that describe their functional relationship to cognition. Using this scheme, methods are classified as activating, modeling, or short-circuiting cognitions that are sufficient for learning. These categories imply a continuum along which instructional methods vary in the information processing demands that they place on the learner, in the extent that the learner controls the instruction, and in the intrusiveness of the intervention.

At the least intrusive end of the continuum are methods that activate. These are approaches that prompt students to use cognitive skills and motivations that they already have and that are sufficient for learning. Thus, such approaches capitalize on student abilities and interests. Laboratories, field research, and internships may provide important tools and resources for students, but they also make the largest information processing demands on them.

The most intrusive instructional methods are those that short-circuit cognitive representations and operations. These methods actually take on the information processing burden of learning by performing cognitions for the learner. They compensate for learner deficiencies in skill or motivation by doing for them what they cannot or do not do for themselves. This is the kind of instruction typically associated with computer-assisted instructional tutorials or programmed instruction.

In the middle of the continuum are methods that model. These methods demonstrate, guide, and direct cognitions but leave much of the information processing burden to the learner. Rather than short-circuit cognitions and motivations that are sufficient for learning, methods that model are intended to remediate the deficiencies by developing in the learners enduring skills and values as well as knowledge. Simulations and other guided experiences may provide such models.

In this report we construct a taxonomy of symbol systems and control capabilities that can be used to create profiles that describe, distinguish, and define various media. A taxonomy of methods provides a means of describing the cognitive effects of instruction. A taxonomy of designs combines media and method to describe which capabilities are used in a particular presentation to what cognitive effect. Our intent is that these descriptors can also be used to describe, "non-mediated" treatments, such as teacher-led discussions or peer-tutoring, thus allowing functional comparisons and contrasts of various instructional approaches.

Medium and Method

As Clark (1983) points out medium and method are confounded. To understand the potential impact either bring to learning, it is necessary to understand the nature of this confounded relationship. We outlined above a way to define and distinguish a particular medium in terms of its capabilities to process (i.e., control capabilities) information (i.e., symbol systems). These capabilities and symbols correspond to certain operations and representations in the learner. Methods are strategies that vary in the information processing burden that are placed on the learner. The distinction between **capability** and **use** of these capabilities allows us to understand how medium and method are confounded.

The melding of capability and use, of medium and method, is design. An instructional design is the use of particular capabilities of a medium for a particular method. That is, a medium presents a range of capabilities to the designer who determines which capabilities will be used to activate, or model, or short-circuit cognitive activities of the learner. The process could, and perhaps should, go the other way. That is, the designer could determine the desired effect and look for the best medium, or media, to accomplish it. In either case, the characteristics of the medium, once selected, serve as limiting boundaries for the instructional design; the design of the instruction can do no more than the medium will allow. The relations among medium, method, and design are illustrated in Figure 1.

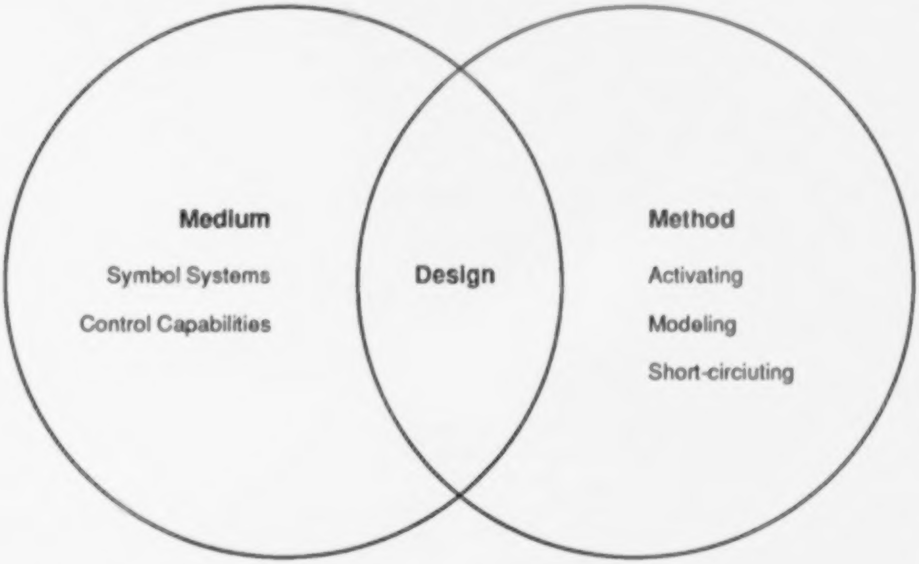


Figure 1. The relationship between medium and method.

Although the relationship between media and design can be a limiting one, it may also be enabling. The introduction of new capabilities with the invention of a new medium can actually spark new design concepts. Yet historically, the influence is more evolutionary than immediate. The design initially used with a new medium is frequently quite similar to that used with earlier, related ones (for example, the initial similarity between film and stage productions). The capabilities of the new medium that are shared with the previous media are those first used. Designs which are unique to the new medium come later as its distinctive capabilities are understood.

In the next several years, we plan to investigate the relationship between methods and the capabilities of computers. We are particularly interested in examining the new issues and concepts of design that may be possible because of the unique capabilities of this medium.

3. Interaction with Context

Context

The selection of media and method is not the only question in design. Presentations are not "well designed" unless they account for the context in which they are finally implemented. One reason that results in the Kulik reports may understate the contribution of media to learning is that individual differences among learners or other contextual variables may obscure the effects of a particular instructional treatment. For example, the use of one medium may work best for learners of a certain type, say those with high ability, while the use of a different medium may work better for learners with low ability and actually interfere with the learning of high ability students. When study findings are averaged, the media/context interaction may cancel out the effects of each treatment such that there appears to be no difference between them. Looking only at main effects, one would conclude that each medium is as good as the other; in reality, one is better than the other for **some students**. This approach to research on instruction is termed aptitude-treatment interaction (ATI) and is best conceptualized in the work of Cronbach and Snow (1977). ATI represents the complexity of the educational environment, while comparative studies naively assume that learning can be explained by a single factor (e.g., the use of a particular medium). Many of the research designs in the studies reviewed by Kulik examined only main effects and ignored the possibility that the medium examined may have been better for certain students.

The pitfall of looking for main effects to the exclusion of interactions can be illustrated with a study by Goodson (1975) who compared computer-assisted instruction and "traditional instruction" in a college course in linear equations. One group of randomly assigned students received tutorial instruction on the computer for six weeks, another group received lectures on the same material for the same period. There were no differences between the groups on the outcome measure, (achievement tests). To stop here one would conclude that it does not matter if you use lecture or computer, either will do. However, when Goodson looked at students' majors the picture was quite different. For students majoring in engineering (i.e., those who used computers regularly), the computer-assisted treatment resulted in significantly higher scores than the lecture. On the other hand, business majors who received computer-assisted instruction actually did slightly worse than those in the lecture group. Such a finding has important implications for the assignment of treatments to students. Operating on a conclusion that these treatments are equivalent could have unfortunate consequences for one group or the other.

"Different media and methods for different people," has a lot of intuitive appeal. However, its logical extension creates a considerable problem. The problem can best be illustrated by examining another study. In a study of unique design, Porteus (1976) examined the interaction of several student variables with "student-centered" and "teacher-centered" treatments. The students in the study were subjected to these treatments in two different courses: economics and educational psychology. The student variables examined were ability, motivation, and anxiety. Porteus found that on midsemester examinations in the economics course, students who were both able and anxious as well as those low in both ability and anxiety benefitted most from the "teacher-centered" approach. Economics students who were high in ability and low in anxiety or low in ability and high in anxiety did well with the "student-centered" treatment. In the educational psychology course, there were no such interactions for the same students until the end of the course. On the last exam there was an interaction with a pattern like that in the economics course. Let us look at several features of this unusually designed study: 1) There are several student variables examined; ability, anxiety, and motivation (although the last did not enter the interaction described). 2) There were interactions **among** the student variables as well as **between** student variables and treatments (ability interacted with anxiety). 3) There were interactions between type of subject matter and treatment (an interaction that appeared in the economics course did not appear in the education course, at least at first). 4) There was an interaction with time (an interaction that did not appear at the beginning of the education course, appeared at the end).

All of these features highlight the major problem with the aptitude-treatment interaction approach to instructional research: the many variables entering an interaction and the multiple interactions among these variables may become unmanageable. There are a variety of ways that college students differ (such as age, ethnicity, socioeconomic status, personality, ability) and these variables can be compounded by differences in learning tasks and instructional situations. Potentially any or all of these can interact with each other and with the treatments. As Cronbach (1975) points out, the ATI researcher enters a potential "hall of mirrors." And as unmanageable as this would be for instructional researchers and theorists, it is an order of magnitude more so for practitioners with more limited resources and information.

Two strategies are important to resolving this dilemma. One is to identify those differences that make a difference; that is, to identify the fewest contextual variables that would be the most likely to interact with a treatment. The second is to look for interactions in the context at hand rather than to try and explain all situations.

In this report, we will highlight the work that has been done on identifying the most salient differences among learners, tasks, and situations. This will serve as a taxonomy of attributes that can be used to describe educational contexts. A tremendous amount of research has been done on learner differences during the past ten years. We will review this in a necessarily cursory way, highlighting important aptitudes while referring the reader to other works for more detail. Much work has been done on differences in learning tasks. We will summarize this work as well. Very little has been done on instructional situations in higher education, but we will identify areas of promise that call for additional research.

The glue that binds this diverse set of contextual categories together is their relationship to learner cognition. The major development in research on student aptitude in the last ten years has been their conceptualization in terms of differences in cognitive processes (Federico, 1980; Glaser, 1980). Aptitudes such as ability, anxiety, and even motivation are now all being described from a cognitive perspective. These characteristics have more obvious relevance to learning than differences in age or socioeconomic status. Likewise, the description of learning tasks in terms of their cognitive demands is a more useful taxonomy than one based on the structure of the disciplines and traditional curricular divisions (Gagné, 1984). Instructional situations can also be described in terms of their cognitive requirements, although traditionally, this is not the practice in the literature. The cognitive implications of differences among learners, tasks, and situations will serve as the foundation of our taxonomy of educational contexts.

The second strategy for resolving the dilemma presented by the potential for unmanageable interactions is to move away from nomothetic laws. That is, instructional research and theory is unmanageable if one is attempting to account for phenomena in all possible situations, to achieve some grand equation that comprehensively qualifies the relationship between treatment and outcome. Much more practical and useful is a process for determining which treatment works best in a given context (Cronbach, 1975). Viewed from this perspective, design becomes both a noun and a verb. A design is a particular instance of the melding of media and method—a science film, an economics computer simulation, etc. To design, one engages in a process of formulating methods and media for a particular instructional context. It is this process to which we turn next.

Designing for Context

Glaser (1976, 1982), building on the thoughts of psychologists as disparate as Thorndike, Dewey, and Simon, begins to outline a science of design, a science that links theory and practice. Generally stated, design is the process of solving problems, of devising courses of action aimed at changing existing situations into preferred ones, of synthesizing artifacts to attain goals (Simon, 1981). It is a prescriptive science as contrasted to the descriptive sciences of chemistry, physics, sociology, and psychology. Yet knowledge gained from the descriptive sciences may be a source of solutions for the designer. More specific to education, we can use our understanding of how people learn and how they are motivated to design instruction to facilitate this process.

Glaser (1976, 1982) identifies four components for a science of instruction. The first is to analyze the nature of the task; what knowledge, or information structures, is needed, and what cognitive strategies and procedures are applied to this information? The second component is the need to specify the learner's initial knowledge and skills, both general cognitive skills as well as knowledge specific to the task. This step can be extended to include the description of other learner and contextual variables. The third component is to describe the transformation processes from initial state to desired state and to construct the conditions that foster this transformation. Such conditions include media and methods. The final component is assessment and monitoring. These are ways to determine the extent to which the design has solved the problem, or how it might be usefully modified and improved to do so.

It is the application of the design process that reduces the magnitude of the ATI problem yet retains an adequate representation of the complexity of the educational endeavor. The designer is not confronted by all possible interactions, but by a specific and circumscribable set. The professor must fashion an instructional treatment for a particular learner (or group of learners), a particular task, and a particular situation. The software developer must state for which learners, tasks, and situations the program was designed.

Design, presented in Figure 1 as the melding of media and method, is now extended to "design within context." The design is the selection of a particular medium and method for a specific learner (or specific group of learners), task, and situation. The elaborated relationship between media, method, and context is depicted in Figure 2.

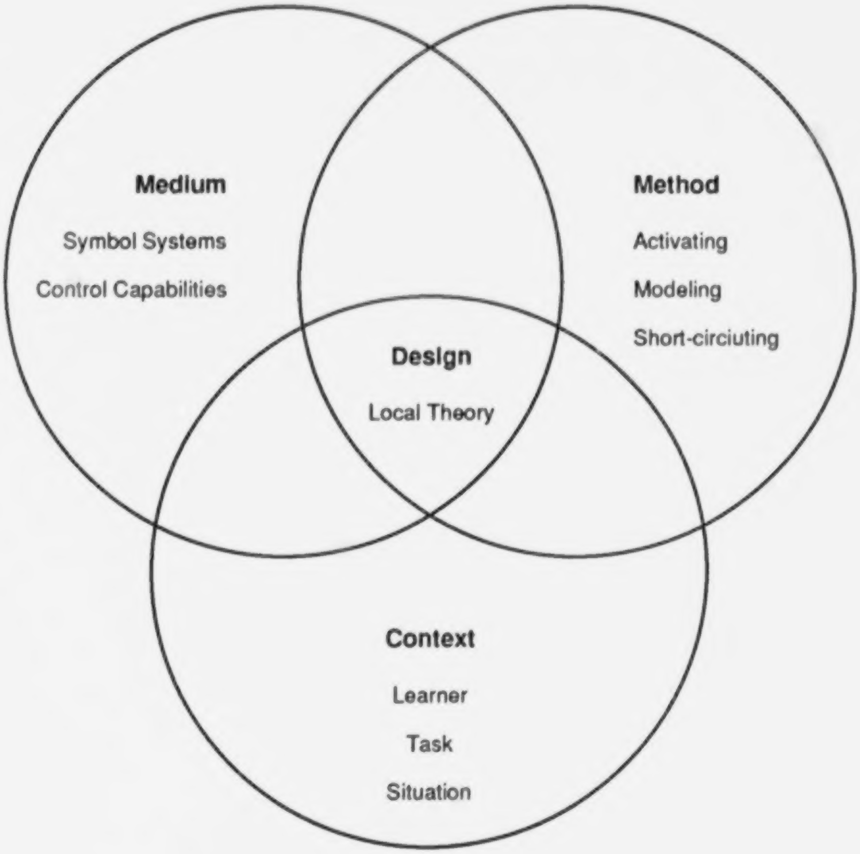


Figure 2. Design as local theory: Medium and method in context.

From this perspective, the professor becomes a designer, a theorist, a researcher. The design is a hypothesis, a local theory if you will, of how the capabilities of the medium will be employed in a particular presentation to activate, model, or short-circuit the cognitions of a learner of certain abilities and motivations in a way that meets the cognitive demands of the task, within certain constraints, resources, or requirements of the situation. As with all hypotheses, this local theory needs to be tested and it is subject to modifications and refinements as more information is gained about the medium, method, learner, task, and situation, and about how these elements work together and are interrelated. For this reason, testing and monitoring is the important hinge upon which the process of design turns.

To formulate a local theory, a designer needs a vocabulary to describe both the particular problem and context at hand and the various solutions that might be devised. The designer also needs some model that relates the problem and solution and mechanisms for assessing changes. Our intent in this report is to construct a taxonomy of media, methods, and contexts and to identify processes that relate them. These can serve as tools that faculty members and designers can use to fashion their solutions to educational problems. Similarly, educational researchers can describe treatments, subjects, tasks, and situations in terms that have theoretical power and functional symmetry.

II. Taxonomies of Instructional Contexts and Design

4. Purpose of a Taxonomy

A number of instructional researchers have identified the lack of and need for a taxonomy of instructional treatments (Clark, 1975; Cronbach & Snow, 1977; Shuell, 1980; Tobias, 1981). In their comprehensive review of research on aptitude treatment interactions, Cronbach and Snow (1977) conclude that "taxonomies of instructional treatments are almost totally lacking" (p. 164) A large number of terms exist to describe instructional treatments (different media, teacher behaviors, classroom environments, etc.) but they are not, by and large, organized systematically or theoretically. Bringing structure and theory to a taxonomy of instructional treatments or designs has both scientific and practical implications.

Utility of Taxonomies

It is not an overstatement to say that the development of taxonomies has corresponded to the development of scientific thought (Simpson, 1961). Their use provides schemes by which observed phenomena can be described and organized. They facilitate explanation, prediction, and the formulation of theories and hypotheses. They prompt the conception of underlying structures that account for class inclusion or exclusion and of relationships between different classes. Thus, not only do alkali metals, to draw on an example from chemistry, have a great many properties in common (they all combine energetically with oxygen, decompose in water, form strong basic oxides, etc.) but this grouping is based on a certain configuration of atomic structure, variations of which account for other chemical groupings with their own characteristic properties. Chemical classes such as alkali metals predated but led to the formulation of the more theoretically based periodic table of atomic structure, which reciprocally led to both a better understanding of alkali metals and the creation of other chemical groupings.

It is the lack of underlying theoretical structures in present descriptions of instructional treatments that has reduced the effectiveness of instructional research (Clark, 1975; Cronbach & Snow, 1977). Much has been done to classify learner and outcome differences but without a scheme to describe treatments, instructional research is incompletely conceptualized. As Shulman (1970) points out, aptitude-treatment interaction research will likely remain an empty phrase as long as aptitudes are measured by micrometer and treatments are measured by divining rod. A taxonomy of instructional treatments based on current instructional theory can increase the power and reliability of instructional research and can in turn advance the development of theory.

Taxonomies have practical as well as scientific applications. An essential basis of categorization of objects is their personal use (Mervis & Rosch, 1981) and their cultural utility (Raven, Berlin, & Breedlove, 1971) as exemplified by the practice of early Greek herbalists to classify plants by their curative properties. Taxonomies can facilitate communication among practitioners about mutually familiar objects and processes, can allow for distinctions among these that have practical significance, can provide an economy of memory in the storage and retrieval of information, and can facilitate prognosis and the selection of treatments.

Pharmacists, physicians, engineers, and lawyers are among the professions who have developed schemes to classify the phenomena with which they work and formalize their practice. The potential exists for educators as well. Unfortunately selection of instruction applications is not presently done so systematically, at least not in higher education (Kozma, 1985). Faculty members more often adopt new instructional approaches based on personal philosophies or preferences than on analyses of the qualities of treatments and their correspondence to learners, tasks, and situations. A structured classification of instructional treatments could facilitate the exchange of ideas and experiences among teachers, designers, and researchers and promote the careful matching of treatments to situations.

Structure of Taxonomies

A taxonomy is a system by which categories are related to one another by means of class inclusion (Mervis & Rosch, 1981). A taxon is a set of objects recognized as a group in such a classification scheme (Sokal, 1974) and taxa are all such groups in the same rank or level.

The bases by which taxonomies have been structured has changed through history (Simpson, 1961). Early taxonomic structure was based on Platonic and Aristotelian deductive notions of defining a species by its "essence," composed of its "genus" (idealized pattern shared by a group of species) and its "differentia" (the part of its essence peculiar to the species). Thus the structure is hierarchical with lower patterns including logical variations on the theme of the higher pattern. Class inclusion is based on inherent attributes or properties of the object. The taxonomy is comprehensive and categories are disjoint, orthogonal, non-overlapping, and mutually exclusive. This is termed a monothetic classification scheme (Sokal, 1974). Monothetic classifications are those in which the classes differ by at least one property which is uniform among the members of each class.

An example of this type of structure is the taxonomy of geometric shapes. The taxon "triangle" is distinguished from others in the taxa "polygons" by the number of sides (three) that are common to all its members. Subordinate taxa are "scalene," "isosceles," or "equilateral," distinguished by the relative lengths of the sides. A particular polygon would be classified as "isosceles" if it had all of the properties of a triangle and, in addition, two and only two of its sides were of equal length.

Most modern taxonomies are polythetic classifications (Sokal, 1974), where taxa are groups of individuals or objects that share a large proportion of their properties but do not necessarily agree in any one property. Membership may be overlapping and boundaries fuzzy. Taxa are not defined by attributes but by relationships (Simpson 1961). The observed attributes held in common by the members of a taxa are viewed as evidence of the underlying defining relationships.

An example of a taxonomy based on underlying relationships is the periodic table, based on atomic structure. A specific example of the shift from early to modern taxonomy is the movement from zoological classification based on morphology to that based on phylogeny, which actually accounts for most morphological similarities and differences.

The shift from deductive to empirical, from monothetic to polythetic, from attribute-based to relationship-based criteria liberated taxonomy from requirements of deductive formalism that worked for logical systems, like geometry, but were problematic from the start for natural systems (Simpson 1961). This shift corresponded to and was facilitated by the development of advanced statistical techniques such as factor, cluster, and discriminant analyses. In these analyses, phenomena are grouped by their characteristic profiles of weightings or correlations on variables that may be shared, more or less, by all of them.

As important as this shift was for natural systems, it is even more so for artificial, or man-made ones. Rather than needing to be comprehensive, orthogonal, and internally consistent, a criteria of "relationship" results in taxonomies of artifacts that are structured by "function." Thus chairs, for example, are objects that are classified by the **number of people that they seat** (i.e., one), rather than by attributes such as the number of legs, arms, etc.

Implications for a Taxonomy of Instructional Treatments

This shift in taxonomy from attribute-based to relation- ship-based criteria is an important one for instructional treatments, which are artificial systems. Because instruction is a process intended to influence learning, it is appropriate that the distinctions in a taxonomy of instructional treatments be based on their relationship with learner cognition. Thus, as Clark (1975) suggests, the attributes of media are derived from functional relationships to the characteristics of learners and tasks. Such a taxonomy is based on the psychological effects of media (Salomon, 1974), rather than their hardware features, and fosters research on media as contrasted to research with media (i.e., research that happens to use a medium). A taxonomy so structured can contribute to the development of instructional theory and the improvement of instructional research.

Furthermore, releasing the requirements of completeness and orthogonality from a taxonomy acknowledges the realities of research in this domain. It allows for the creation of useful descriptors that may account for much of the variance in the phenomena without having to account for every case. It also acknowledges the confounding of phenomena in the real world. The taxonomy can describe media and method, cognition and motivation even though they are not independent.

Presented in this section are base taxa of media and method attributes that can be assembled into clusters or profiles of higher level taxa of instructional designs or treatments that are functionally matched to a corresponding taxonomy of instructional contexts defined by lower level taxa of learner, task, and situation attributes. So, for example, a micro-economics computer simulation can be described in terms of the calculation (control capability) of profits from business decisions concerning production and advertising. This information can be presented in graphic form (symbol system) to model (method) these relationships for students who are not high in quantitative ability but are high in spatial ability and who are learning the dynamics of the market economy (characteristics of the context). Although the taxonomy is used to describe a design that employs a medium in this example, other forms of treatments, such as lecture and group discussion, could also be described in terms of symbol systems, control capabilities, and methods that are employed.

For practitioners, the taxonomy can serve as a checklist or tool kit that suggests various possibilities for the design of instructional systems. For the researcher, it presents a vocabulary that can be used to describe instructional treatments and contexts. A common, theoretically-based vocabulary used by individual researchers in independent, disparate studies can provide a scheme for the integration of results and the evolution of a more comprehensive theory of instruction from diverse local theories (Shuell, 1980). A vocabulary shared by both practitioners and researchers can promote the utilization of scientific knowledge and the ecological grounding of research.

Let us make an important qualification. The taxonomy offered here is just a beginning. Although the attributes listed in the taxonomy are intended to capture the most salient differences among media and methods, it is important to remember that media and methods are artifacts that have themselves been designed. Others will no doubt be designed in the future and may give us additional capabilities and functions not represented in the current taxonomy. Our taxonomy is also a design. It is a set of constructs that can be used to devise solutions for researchers and practitioners. It will be extended, modified, and revised based on its application. This is meant to acknowledge, and hopefully avoid, an implicit risk in the use of taxonomies, that by specifying where one will look, one looks only there.

5. Instructional Contexts

Our intent with this section, is not to break new ground. Rather, we want to survey the current research and theory on three important elements of the instructional context: the learner, the task, and the situation. We will describe differences within each that have implications for instructional design. At the same time we will draw parallels across elements and between elements of the context and elements of instructional treatments, in an effort to integrate research and theory that has different historical roots and foundations. These relationships remain tentative and hypothetical, subject to validation in various local contexts.

Learner Aptitudes

Professors are used to thinking of their students as sophomores or seniors, or majors or non-majors, or perhaps as bright students or underprepared students. To the extent that these intuitive terms have utility it is because they correlate with other, more theoretically powerful constructs having to do with learning.

The last twenty years has seen an emerging consensus within psychology around the description of learning in cognitive terms (Greeno, 1980; McKeachie, 1976). A number of psychologists comprehensively describe the structures and processes of learning (Klatzky, 1980; Estes, 1978; Glass & Holyoak, 1986), but Gagné (1985) represents a useful summary of these in his listing of the events of learning:

- attention
- selective perception,
- rehearsal
- semantic encoding
- retrieval
- response organization
- feedback

These events are considered to be essential to learning and common to all learners, and instruction can be designed to correspond to commonalities in processing (Bovy, 1981; Gagné & Briggs, 1979). But learners can be usefully classified by their differences (i.e., their aptitudes) and these have additional implications for instructions (Cronbach and Snow, 1977).

Cronbach and Snow define learner aptitudes quite broadly to be any individual differences that may affect learning. These aptitudes are increasingly viewed less as fixed capacities and more as mutable differences that influence cognitive processing (Federico, 1980; Glaser, 1980). Corno and Snow identify three classes of such aptitudes: cognitive skills; personality or affective characteristics; and conative attributes, or propensities for processing information in certain ways (Snow & Lohman, 1984; Corno & Snow, 1986). The literature on individual differences is immense and the reader will benefit from examining the more comprehensive review by McKeachie, Pintrich, Lin, & Smith, (1986).

Cognitive Skills

For some time, Cattell argued that intelligence as measured on aptitude tests could best be understood, not as one general factor, but as two cooperative factors (Cattell, 1963). He called one factor "crystallized" ability because he believed it to be "skilled judgment habits. . . crystallized as a result of earlier learning application of some prior, more fundamental general ability to these fields (p. 2-3). Fluid ability, on the other hand, was thought to be closely related to or even synonymous with the fundamental general ability and is most apparently exercised in new situations where crystallized ability gives no advantage.

More recent factor analytic studies of aptitude tests have confirmed the distinction between crystallized and fluid abilities. For example, Snow (1980a) reported his analysis of data from 241 high-school students and found evidence that the students were using these two types of abilities to generate responses to different aptitude test items. Snow also determined that a distinct third factor was involved in answering figural and spatial relations items. He called this factor "visualization."

Because Snow and his colleagues have clarified earlier definitions of crystallized ability, fluid ability, and visualization and attempted to relate these aptitudes to instructional treatments, we borrow heavily from them in our conceptualization of learners' cognitive aptitudes. Snow emphasizes that aptitudes are not static phenomena, but adaptive processes or even classes of processes. They manifest themselves differently depending on the instructional task and will change over prolonged exposure to different instructional treatments. A learner may shift from one ability to another in the course of instruction. Though ability types are distinguishable, they operate in conjunction with each other to help a learner adapt to new learning tasks, to process information, and to solve problems.

Crystallized ability. Crystallized ability is the factor associated with performance on tests of verbal knowledge, reading comprehension, and prior educational achievement. It is developed and called upon under conditions of formal education (Corno & Snow, 1986) and is therefore a very good predictor of academic success. Because of its close association with school instruction, British theorists call this same aptitude "verbal-educational ability." Crystallized ability seems especially relevant to learning where meaningful understanding of complex material is required.

Successful performance on tests of prior achievement require two conditions: specific prior knowledge necessary to respond to test items and sufficient skills to comprehend the questions and retrieve the necessary information (Corno & Snow, 1986). Tests of crystallized ability measure the presence of the knowledge and the operation of various processes needed to generate a response. However, the ease or difficulty that a learner may have with a particular task may be due not to the sheer amount of accumulated prior knowledge but to the presence or absence of one or more specific facts or cognitive skills that are directly relevant to the final performance (Gagné, 1985). Important differences in crystallized ability among students may be very specific in nature, for example, differences having to do with knowing facts about certain chemical reagents or being able to determine rates of reactions. Tobias (1976, 1981) reviewed research which indicates that those students who lack specific, relevant prior knowledge benefit more from additional instructional support.

Fluid ability. Fluid ability (Cattell, 1971) is a factor consisting of abstract and sometimes nonverbal reasoning of the sort measured in problem solving tests and some spatial and figural tests. It is not tied to any particular acquired learning or previously experienced tasks, but represents the ability to generate solutions to novel and complex problems. Thus it may relate to and benefit from learning under conditions of new or unusual methods or content (Corno & Snow, 1986).

Fluid ability is generally correlated with both crystallized ability and visualization (Snow & Lohman, 1984). Almost all instructional tasks require the cooperative activity of both analytical skills (fluid ability) and verbal skills (crystallized ability). Similarly, many problems in spatial relations are novel problems that require analytical skills for solution. Not surprisingly, both fluid ability and visualization skills correlated highly with performance on such items.

However, fluid ability is qualitatively different from crystallized ability and visualization. Crystallized ability and visualization differ primarily in the types of symbolic representations they operate on, verbal or spatial symbols respectively. Fluid ability results in "the flexible adaptation of either of these kinds of assemblies, and their integration in complex performance (p. 360)." Fluid ability is thus "higher" than crystallized ability and visualization, involving reasoning that is more abstract and complex and dependent to some degree on the skilled performance of the "lower" aptitudes. Fluid ability seems to develop somewhat earlier than crystallized ability and is associated with performance in informal learning settings as well as formal educational settings.

Spatial ability. Spatial ability, or visualization, refers to specialized skills for processing of complex figural and spatial information. This ability is typically measured by tests of the mental transformation of spatial relations and spatial orientation. Spatial ability is factorially tied to fluid and crystallized ability, in part because test items can frequently be solved either by spatial or verbal strategies.

As with crystallized ability, a distinction can be made between general spatial ability and the visual representations of a specific learning task. Paivio (1974, 1979) describes a dual coding process of learning and memory. One system is verbal and is specialized for dealing with linguistic units and generating speech, the other is specialized for representing and processing information concerning nonverbal objects and events as images. The verbal and visual systems are functionally independent in that information may be stored in one symbol system without necessarily being stored in the other symbols.

However, if information is represented in both verbal and visual symbols, the effectiveness and efficiency of cognitive processing can be increased. Though the two systems are independent, they are also interconnected. The imaging system frequently interacts with the verbal system such that images can be manipulated under verbal direction or nonverbal data can be stored in association with verbal labels or descriptions. Verbal symbols can be used as cues to complex images or images can be used to encode the equivalent of large amounts of verbal information. By storing information in both symbolic modes, the likelihood of successful retrieval of information is increased. Furthermore, different tasks may make different cognitive demands on learners and these demands may be related to whether information is represented in verbal or visual form. When information is stored in both systems, a learner activates the type of representation that facilitates solutions most efficiently (Kosslyn, 1981, 1983).

Thus, there are several ways that learners may vary in their performance on tasks with visual components. They may differ in:

- their ability to manipulate visual symbols
- their visual representation of information relevant to the task
- their verbal representation of information relevant to the task
- the ease with which they connect visual and verbal information

Conative aptitudes and metacognitions

Gitomer and Glaser (in press) equate earlier notions of conation to the present day notions of executive mechanisms and self-regulatory behaviors, such as the metacognitive strategies discussed by Brown, Bransford, Ferrara, & Campione (1983) and (Flavell, 1979). Learners that exhibit these strategies have a greater awareness of the demands of a task, the nature of the materials, their own capabilities, and the activities which can be performed to accomplish the task. Furthermore, such learners are aware of the interaction of these factors, and can use that knowledge in flexible, purposive ways.

Gitomer and Glaser (in press) studied the differences in strategies used by high and low ability learners. They found that low ability learners are often deficient in the knowledge needed for competent performance. Along with this deficit, are apparent conative, self-regulatory differences which are manifested on more difficult tasks. Low ability learners do not adjust to problem difficulty as flexibly as high ability learners and do not maintain their processing until the task demands are satisfied.

The interconnectedness of these aptitudes presents some definitional problems. Because they are generalizable, flexible, and related to performance in complex tasks, metacognitive skills are difficult to distinguish from fluid ability. Thus metacognitive strategies may more appropriately be classified as high-end cognitive skills rather than conative aptitudes. On the other hand, there is a strong component of motivation, persistence, or affect in the pattern found by Gitomer and Glaser. The question then becomes, what exactly is conation, cognition, affect, or a distinct aptitude?

Perhaps a sufficient resolution is provided by Corno and Snow (1986) who describe conative aptitudes as propensities for processing information in certain ways that develop around particular ability-personality intersections. These propensities differ from but are constrained by one's enabling competence (intellectual ability) and enduring disposition (personality). Thus conative abilities can be seen as the intersection of cognition and affect, a lack of disjointedness permitted by modern taxonomic practice.

Motivational Aptitudes

Motivational aptitudes are those that account for the learner's initial engagement in learning tasks and for subsequent persistence, particularly in reaction to initial failure. An important shift in the literature on personality characteristics has been the conception of these factors in terms of cognitions. Casting these constructs in cognitive terms has moved the psychology of learning and personality psychology toward a unified theory.

The following represent alternative models of motivated cognition. While they may be seen as competing conceptualizations, it is more likely that they are all more-or-less accurate, and cognition can be motivated by any of a number of interacting mechanisms.

Attributions. Attributions are the explanations that students give for their performance or the performance of others. Attributions may not always be articulated; i.e., they may be unspoken assumptions that students have about their own or others' behavior. Attributions determine people's feelings about themselves, their predictions of their success in a given task, and the probability they will try harder or less hard at the task in the future. Weiner (1980) identifies four reasons that learners most commonly give for success or failure in an educational task: ability, effort, task difficulty, and luck. Each of these corresponds to kinds of attributions that learners make:

- Locus of causality (internal or external). That is, is the cause for success or failure attributable to the effort or ability of the learner or to some external factor?
- Stability (stable or unstable). Does a given phenomenon occur reliably or is its occurrence attributable to chance?
- Controllability (controllable or uncontrollable). Are circumstances necessary for success in a given situation under human control?

Attributions can work in complex interactions. For example, students who view academic success as personally caused, likely to recur (stable), and within human control, will be inclined to have higher performance expectations and to exhibit motivated behavior. On the other hand, students who view academic failure as personally caused, unlikely to be remediable (i.e., stable), and outside human control are likely to reduce performance expectations and motivated behavior. Yet, if the learner attributes a particular failure primarily to the unstable action of chance events, he or she is likely to persist.

Self-efficacy. Self-efficacy is defined as a person's estimate that a given behavior will lead to certain outcomes (Bandura, 1977). Self-efficacy theory suggests that initiation of a behavior and persistence is based more on the strength of belief in one's ability to perform than on either task incentives or actual personal skill. Assessment of self-efficacy can rest on previous attributions. That is, self-efficacy is stronger when past successes are viewed as resulting from personal control. However, self-efficacy can also be derived from a knowledge of the performance of referent others (that is, others seen as similar to the self) who perform well or attest to their own success.

Intrinsic and extrinsic motivation. Many authors distinguish between two motivational orientations, intrinsic and extrinsic (e.g., Csikszentmihalyi, 1978). Intrinsic motivation is motivation that emerges directly from experience with a task or object. An intrinsically motivated student does not appear to be working for a particular reward but for the sheer enjoyment of the activity at hand. Extrinsic motivation, on the other hand, is directed toward the achievement of "fixed" goals, rewards that are biologically and socially determined and are obtainable by the accomplishment of a specified task.

Individuals may tend toward one or the other motivational orientation. One student may regularly engage in learning tasks without receiving rewards and punishments while another student may be uninterested in education without obvious reinforcement contingencies to direct his or her behavior. However, intrinsic and extrinsic motivation are probably more typically task-specific. That is, a particular student may be intrinsically motivated to do mathematics homework, but need fixed goals to accomplish readings in biology.

Another important point to make is that it is generally assumed that it is better to foster intrinsic motivation than extrinsic motivation. An extrinsically motivated student may accomplish assigned instructional goals, but only as a means to some other end. The student will be uninterested in doing any but the minimal work necessary to get the reward, is less likely to retain what was learned, and is less likely to pursue learning in everyday life or when given similar tasks without rewards. An intrinsically motivated student will often do more than what a teacher deems necessary for an assignment, will retain what is learned longer because it is more personally meaningful, and will be motivated to learn similar material in everyday life and without apparent rewards.

Recognition. Recognition is a motivating force in the behavior of virtually all human beings. However, individuals can differ in the degree to which they need recognition. Need for recognition can be described in various, perhaps slightly different senses: need for affiliation, for approval, for achievement, etc. It is also important to note that recognition can operate in both intrinsic and extrinsic motivation. A student who has a high need for recognition and is extrinsically motivated in a particular task may seek to be successful in the task, not because he or she finds the task enjoyable in itself, but for the sake of the approval of peers or significant adults. However, even in intrinsic motivation, it is necessary for at least the activity to have a meaningful social context in order to be motivating. Though other people need not be present when the activity is performed, their concern about the activity lends a larger reality to the individual's performance. In this meaningful context of social recognition, an intrinsically motivated learner will be able to find all sorts of personal rewards and pleasures in the performance of an instructional assignment.

Anxiety. Anxiety refers to the set of affective, physiological, and behavioral responses that accompanies an event in which an individual perceives that he or she may be unable to deal easily and satisfactorily (Sieber, 1977). Perception as part of the definition draws in attributions of task and self which are mediated by estimates of success. Optimal levels of anxiety can motivate improved performance; beyond this level they are dysfunctional (Yerkes & Dodson, 1908). There is also good evidence that the optimal level of arousal is inversely proportional to task difficulty (Eysenck, 1982).

Tobias (1977) describes the cumulative cognitive effects of dysfunctional anxiety on preprocessing, processing, and performance. In preprocessing, anxiety may incapacitate learners' attention to target stimuli. Anxiety may also reduce the learner's ability to recall important prior knowledge, and anxiety-related cognitions may compete for limited space in short term memory. Finally, during performance, anxiety may interfere with the accurate rendering of the response.

Learning Tasks

Professors, being chemists, anthropologists, and so forth, are likely to see what they teach in terms of their discipline, bound by its structure and its development. From this perspective, what is taught in chemistry is very different from what is taught in anthropology. Psychologists, however, are likely to see similarities in the tasks students face across disciplines, and to see more differences between certain tasks within disciplines. These differences and similarities are in the processes by which the tasks are learned, and thus, they have different implications for the way they are taught (Fleming & Levie, 1978).

There is a fair amount of convergence among theorists about the classification of learning tasks. Gagné (1984) identified five types of learning:

- verbal information (declarative knowledge)
- intellectual skills (procedural knowledge)
- cognitive strategies (executive control)
- attitudes
- psychomotor skills

These categories generally parallel the more traditional distinctions made by Bloom (1956) among cognitive, affective, and psychomotor domains. There is also a rough correspondence between the first two or three categories and Merrill's (1983) categories of "remember," "use," and "find." The first two categories correspond to distinctions that Anderson (1976) makes between declarative and procedural knowledge.

Gagné's scheme for describing learning tasks has provided an important framework for this taxonomy of instructional tasks, but we hope to enlarge Gagné's conception. Traditional discussions of learner aptitudes have not been integrated with schemes for instructional tasks, the belief being that aptitude tests measure very different skills from scholastic achievement tests. We would prefer to think of learner abilities, measured by aptitude and achievement tests as being rooted in the same cognitive activities. The present taxonomy attempts to integrate the discussion of learner aptitudes and school learning tasks.

Declarative knowledge

As Gagné (1984) defines it, verbal, or declarative knowledge is characterized by the ability to "state" or "declare" something. Declarative knowledge is distinguished by specific verbal responses to specific stimuli. Merrill (1983) uses the common sense term "remembering" to describe cognitive performance at this level. This is searching memory to reproduce or recognize items of verbal information that were previously stored.

We regard declarative knowledge as roughly synonymous with crystallized ability. Crystallized ability has been described in terms of verbal knowledge, reading comprehension, and prior educational achievement and this approximates Gagné's use of the term declarative knowledge. As we said about crystallized ability, declarative knowledge includes the abilities needed to "declare," as well as the associated knowledge structure. According to Gagné, declarative knowledge is stored in the form of concepts in a network of related propositions, or a "schema." As learning proceeds, additional links are made with other concepts and other networks of concepts. Increased interconnection among the concepts facilitate subsequent retrieval.

Perception is the first stage in the acquisition of new declarative or spatial knowledge. This first stage [also called selection (Weinstein & Mayer, 1986) and alertness and selectivity (Corno & Mandinach, 1983)] is the focusing of attention on stimuli or information and the transfer of the information to working memory. Perception involves comparison and discrimination (the simple distinguishing between two objects or symbols) and selective encoding (the sifting of relevant from irrelevant information for task performance). Certain tasks (more so in some disciplines than others) may have salient visual features of the stimuli that need to be discerned

The storage and retrieval of information are also vital to visualization and crystallized ability. Storage (also called acquisition or encoding by some authors) refers to the transfer of information to long-term memory. Retrieval refers to the recovery of previously stored knowledge for connection with incoming information. (Some authors have called this process "integration" or "connection".) Storage activities can take place through simple rehearsal and elaboration strategies, and retrieval through simple matching techniques. However, when more sophisticated operations are applied to information in working memory, storage and retrieval processes may also become more complex. For example, when new information is organized according to a classification scheme, storage and retrieval processes may access links among elements of the classification's categories. The higher level processes that may affect storage and retrieval processes are discussed in the next section.

Intellectual skills

Intellectual skills, or procedural knowledge, are rule-governed operations which alter the nature or representation of information in working memory. They are the concepts, rules, and procedures needed to apply verbal knowledge to a range of situations through the generalization of principles. Merrill (1983) defines this kind of cognition as the application of some abstraction to a specific case, "using" knowledge, and as the derivation or invention of new abstractions, "finding" knowledge. (Merrill's "find" category straddles the boundary between "higher-level" intellectual skills and cognitive strategies. Cognitive strategies are discussed in the next section.)

As described by Anderson (1980), procedural knowledge identifies the conditions under which specified actions should take place. In the case of generating plural nouns, for example, a general rule in condition/action form would be "IF the noun ends in a hard consonant, THEN the plural is formed by adding 's'." This rule can be applied to solve a very large number of similar but distinct problems. According to Anderson, learning of this sort progresses in three stages from initial acquisition, to proceduralization, to automatization.

Like all cognitive phenomena, declarative, spatial, and procedural knowledge are not entirely discrete but are dependent on each other. Gagné (1985) contends that the acquisition of procedural knowledge is dependent on the availability of relevant declarative knowledge, and we assume that procedural knowledge regarding visual information requires familiarity with visualization. On the other hand, in performing operations on verbal or visual knowledge, intellectual skills may transform, even enhance, declarative knowledge. Facts or visualized structures may be reorganized or integrated with new information, producing new mental structures.

We regard higher-order intellectual skills as roughly synonymous with fluid ability. As with fluid ability, intellectual skills require the acquisition of and some facility with verbal and visual information. Also like fluid ability, higher-level intellectual skills are generally useful and less tied to any particular acquired learning or previously experienced tasks.

Borrowing again from the language of information processing, we can identify eight specific processes that are included under the rubric "intellectual skills." This list is not meant to be exhaustive. It describes those processes that we think are fundamental intellectual skills and which have been described in the literature by other authors (Gagné, 1985; Weinstein & Mayer, 1986; Sternberg, 1985). The eight processes are:

1. Translation- conversion of symbols to "parallel" symbols

2. Transformation- conversion across symbol systems

3. Mathematical operations-applying mathematical rules to the manipulation of numbers

4. Classification- grouping of symbols according to pre-determined rules

5. Organizing- ordering of symbols according to some rule (chronological, numerical, alphabetical, hierarchical, etc.)

6. Integration/ synthesis/ combination- combining of information

7. Inference- identifying connections between two concepts previously thought to be unrelated

8. Mapping- identifying higher order relations among lower order relations

Cognitive strategies

A cognitive strategy enables a learner to exercise some degree of control over the processes involved in attending, perceiving, encoding, remembering, and thinking (Gagné, 1984). Cognitive strategies are "executive control processes" that can be applied in a wide variety of task situations. We regard cognitive strategies to be synonymous with meta-cognition. Flavell (1979) defines meta-cognition as learning to learn or thinking about thinking and he thus seems to be describing the same constructs as Gagné. Tobias (1982) calls this level of cognition "macroprocessing."

Cognitive strategies or meta-cognitions can be grouped into three categories. Strategies for planning include meta-cognitions that work to anticipate the resources needed to meet specific task requirements and that strategize the expense of resources in the most efficient means. Monitoring activities are cognitive strategies which gather and interpret information about the learner's performance and the effects of that performance. Monitoring activities evaluate the learner's actual performance by comparing it to the anticipated performance. On the basis of monitoring activities, the learner may need to make adjustments in his or her behaviors regarding the learning task. These adjustments, known as self-regulation, are the third category of meta-cognition.

The following is a partial list of cognitive strategies included in the three categories (McKeachie et al., 1986; Brown et al., 1983; Sternberg, 1985):

A. Planning
   1. Definition of task
   2. Generation of questions/hypotheses regarding outcome
   3. Selection of one or more representations of problem
   4. Task analysis
   5. Prediction of ability to retrieve necessary prerequisite information
   6. Anticipation of difficulties and resources needed to resolve them
   7. Strategy for coordination of lower-order processes (prioritizing)

B. Monitoring
   1. Checking direction and level of attention
   2. Assessment of memory capacity and retrieval performance
   3. Sensitivity to performance feedback
   4. Identification of weaknesses in performance or comprehension (self-testing)
   5. Checking timing and quality of progress against anticipated progress or anticipated solution
   6. Identification of environmental factors that are especially debilitating or facilitating of performance

C. Self-regulation
   1. Changes in allocation of attention
   2. Self-talk
   3. Management of attributions
   4. Application of mnemonic systems for improving memory performance (visualization, rhymes, elaborations, etc.)
   5. Review of performance or material to be learned
   6. Self-reinforcement
   7. Seeking help from additional resources
   8. Alteration of environment to reduce distractions and facilitate performance

Attitudes

In our section on learner aptitudes, we discussed how various motivational states can affect subsequent learning. Affective states can also be learning outcomes. Clearly some of the factors that we discussed under the broad definition of aptitudes, factors such as anxiety and the need for recognition, are not typically the targets of education in conventional school settings. Changes in such learner characteristics have largely been considered the domain of psychotherapy. However, most would agree that instruction should have an influence on other affective factors. Instruction, for example, should not only teach students important information and train them in certain cognitive skills, it should also result in positive feelings about the subject matter they are learning, they should be motivated to continue to learn, and they should have realistic confidence in their own learning abilities.

The kind of attributions that students make about their performance or the performance of others can be a result of instructional design. For example, if the relations between student performance and the contingencies of that performance are obscured by the instructional design, the student may attribute progress in a lesson to chance events rather than to his or her effort. Furthermore, the kinds of feedback provided in instruction can train a student to explain success or failure in instruction in certain ways. When a student fails to solve a given mathematics problem, one would expect very different responses to feedback that says, "Try again. You're not trying hard enough." than to feedback that says, "This problem is very difficult. I didn't expect you to solve it." Repeated exposure to a particular attributional pattern in feedback can teach learners to maintain the pattern.

Krathwohl, Bloom, and Masia, (1964) describe the affective domain as emphasizing a feeling tone, an emotion, or a degree of acceptance or rejection. Krathwohl et al. meant this domain to range from selective attention to specific phenomena to complex but internally consistent qualities of character and conscience. Gagné (1984) borrows Allport's definition of these internal states as attitudes that influence the choice of personal action. Attitudes seem to be acquired in a very different way than cognitive outcomes. Presumably they are formed over extended periods of attribution formation and experience with contingencies of reward, punishment, and recognition, and with varying levels of anxiety in the performance of different tasks. Once established, attitudes may persist for many years and may in some cases be highly resistant to change.

Self-efficacy can also be influenced by previous patterns of attributions. Self-efficacy, the belief that one has the ability to accomplish a task, is stronger when past successes are viewed as resulting from personal control. The modeling of successful performance by referent others can also improve self-efficacy. Because it is generally seen as desirable to nurture initiative and perseverance in students, strengthening self-efficacy is an important instructional outcome.

Finally, instruction should make students eager to continue learning either in the conventional school or on their own. This "love of learning for learning's sake" is characteristic of intrinsically motivated behavior. In extrinsically motivated learning, the student has been given obvious external rewards for accomplishing tasks that were defined by the teacher or, at best, in consultations between teacher and student. Learning that has been done for the gain of a fixed, external reward will be discontinued when the reward is no longer available. Because the learning was accomplished for the sake of the external reward, the new knowledge and skills were not personally meaningful.

Instrinsically motivated learning, on the other hand, is self-maintaining because it is stimulated by experience with the phenomena being learned. Instrinsically motivated students do not need rewards to preserver at tasks but generate personally involving goals as they learn. Instructors nurture intrinsic motivation in their students by encouraging students to devise personal goals for their own learning; allowing students to have (or feel they have) some control in the instructional process, especially in establishing the level of difficulty of the instruction; and by sparking curiosity in students by showing inconsistencies or incompleteness in their knowledge and by presenting significant information or skills in a novel way.

Psychomotor skills

Psychomotor learning obviously differs from other types of learning in the motor nature of the performance, but it also differs in the required prerequisites and in the progression of its acquisition. Psychomotor skills require the mastery of component motor skills and frequently require certain physical qualities, such as, size, stature, endurance, and strength. Fitts and Posner (1967) describe three phases in the learning of motor skills. The first is a cognitive phase which refers to the learning of the components and the sequence of the events. The second phase is the associative phase in which the parts come to be fitted together. Finally, the autonomous third phase is when the skill can be exercised in a smooth and fast way without the need for much attention. This level of performance is very much dependent on frequent practice.

Summary

The last two sections have attempted to draw parallels between notions of learner aptitudes and the tasks of school learning. This seems appropriate as increasingly the goal of higher education is to change student aptitudes, and aptitudes are increasingly seen as subject to improvement, and both are viewed in terms of cognitive processes. Figure 3 shows the correspondence between conceptions of aptitude and those of tasks as we have described them. Although there are parallels, there are clearly some discrepancies. This should not be surprising as the two bodies of thought have evolved more-or-less independently. Nor should it be particularly troublesome if the relationships are viewed as heuristic and laying the ground work for future research and thought.

Situations

The learning situation is, in a sense, a default category. It represents those conditions in addition to the instructional design, learner aptitudes, and learning tasks that are immediately present to the learner and which may affect the learner's ability to meet the instructional goals. We view the learning situation as task relevant resources, opportunities, expectations, and constraints beyond the instructional treatment itself. These may come in the form of physical resources and materials, or human resources, such as the professor or other students. Our predilection is to characterize situations by the cognitive demands and requirements that are placed on the learner, particularly those that facilitate or inhibit learning. But much work still needs to be done before an environment can be carefully described in these terms.

College campus

Much of the literature on the psychology of educational environments (particularly college environments) has focused on the macro-system level. Some of the descriptors are strictly demographic (Astin, 1968), and report the size of the student body, the faculty-student ratio, the number of fields in which degrees are offered, etc. Others are more theoretically-based and describe an institution in terms of its prevailing expectations, values, or environmental "press."

Centra's Questionnaire on College and Student Characteristics (1970), Pace's College and University Environment Scale (1963), and Pace's College Characteristics Index (1969) are examples of theoretically-based descriptions of educational environments. They are based on factor analyses of questionnaires given to large numbers of students at many institutions. The questions frequently refer to norms, expectations, activities, pressures, rewards, facilities, and resources that exist on campus.

The names of the factors derived from these scales vary, but there is much overlap. Most scales have factors that refer to a press for academic achievement, humanistic values, vocational goals, social orientation, and conformity. It is assumed that students with needs corresponding to the characteristic press of an institution will be more satisfied and fulfilled than in a mismatched condition. The theoretical foundations of these models come out of a personality or social psychological orientation. Such scales may account for socio-motivational dynamics within the college environment, but they do not have the power to describe the immediate cognitive requirements and demands of the learning situation.

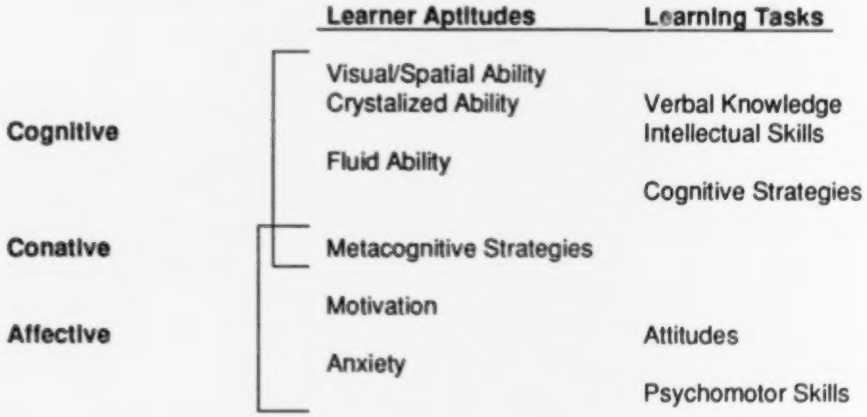


Figure 3. Parallels between learner aptitudes and learning tasks.

The instructor

Much of the professor's influence on learning is through the instruction: the mix of tasks, methods, and presentations that are represented elsewhere in this taxonomy. However, some researchers contend there are certain personal predilections or "teaching styles" that not only directly influence the form of instruction, but the roles and expectations that affect the students' learning. Axelrod (1973) describes four such styles based on observations of college faculty:

- The content-centered instructors teach what they know. Characterized by a deference to their disciplines, they are concerned about covering the material in a systematic way. Their primary interest is in teaching the facts and principles of the field. Students in turn are expected to display their mastery of the material by accurately restating and applying it.

- The instructor-centered prototypes teach what they are. They offer themselves as models of the educated or professional person. They see themselves as representing a certain intellectual or artistic process, which students are invited to emulate. They are overtly involved in role modeling.

- The intellect-centered instructors train minds. For them, knowledge is a process, not a product. The focus of teaching and learning should not be on the products of rational inquiry but rational inquiry itself: the how and why of knowledge rather than the what. They emphasize intellect-rational development and the rigorous use of reason, language, and problem-solving skills.

- Finally, the person-centered instructor focuses on the student as a person. They do not believe that intellectual development can be separated from other aspects of the students' emotional and personal development. They believe that the whole range of a student's growth and development should be addressed by the teaching and learning process.

Afforded opportunities

Different environments, or situations, afford opportunities (or not) for different behaviors. This is the result of a combination of learned expectations of which behaviors and goals are appropriate or not in a given situation, and the resources (or constraints or inhibitors) in the situation that are relevant to certain goals and activities. Books, journals, tables, desks, and chairs are resources that make libraries good places to read and study. Also, students come to know, frequently from other students, that quiet reading, contemplation, or even sleeping (for short periods) are appropriate behaviors for libraries, but playing bridge, for example, is not (even though chairs and tables are useful for bridge playing and books on bridge may be in the library's collection).

These opportunities are mediated by other factors. Certain skills may be required to exploit the opportunities an environment presents, such as the ability to use a card catalog in a library (whether to find a book on bridge or on Plato). Time may be another mediator. Expectations that are appropriate for an environment at one time may not hold at another. For example, playing a stereo in the dorm room may be alright, but not after 11 p. m. The resources or constraints of an environment may be time sensitive; they may be there only at certain hours or only for so long.

Summary

These disparate constructs hardly constitute a taxonomy of learning situations, nor do they seem to have systematic implications for instructional design. Rather, when designing an instructional treatment, these are factors of the environment within which it will be embedded that may be considered. But they do suggest that there are a number of variables in addition to the instructional presentation, learner aptitudes, and learning tasks that will influence the performance of learners as they are engaged in instruction. Much work still needs to be done before an environment can be carefully described in terms of its cognitive demands and requirements. Because they are so particular to a given context, these factors may be more easily built into a local theory than into a taxonomy such as this. However, it is hoped that future research will allow for a more thorough description of factors in learning situations.

6. Instructional Designs

An instructional treatment, or design, is composed of two primary elements: media and method. Each of these can be examined in terms of their attributes. Media attributes include the forms of the information presented through the medium (i.e., symbol systems) and the operations that the medium can perform on the information (i.e., control capabilities). Method attributes, on the other hand, are aspects of the design that determine the role which the medium plays in learning. Types of methods include activation, modeling, and short-circuiting; these vary in intrusiveness and in the amount of informational processing load handled by the instruction. In this section we detail categories and sub-categories of these attributes. As a group, they form a taxonomy of descriptors that can be used to characterize any instructional intervention.

Media Attributes

An instructional medium is anything that transmits information to learners. Instructional media can vary in technological sophistication, but here the term is meant to refer to all information delivery "devices" from the most recently developed microcomputer and videodisc technology to "soft" technologies such as workbooks and texts. All instructional media can be described by two broad sets of attributes: the type of information they can communicate and the way they can process this information, and their symbol systems and control capabilities. Different media may have some attributes in common. Books, films, and television, for example, can all display visual linguistic information (i.e., written text). A unique medium is composed of a cluster or profile of attributes. A medium is unique to the extent that its profile differs from other media. A medium is powerful to the extent that its profile is isomorphic with cognitive processes.

The profile of attributes for a particular medium represents capabilities which **can but may not be** used in a particular design. Which capabilities get used and in which way is a function of the selected method. Exactly how information will be "packaged" for the learner (i.e., what symbols will be used and what operations will be performed on these symbols) is a design decision confounded by the actual capacities of a medium. A medium defines a set of potential instructional possibilities from which the instructional designer may pick to produce a program that best fits a target set of learners, tasks, and situations. The range of instructional possibilities define the media, though a given implementation may make use of only a small part of the medium's capacities.

Describing instructional media in terms of their profiles of symbol systems and control capabilities will give researchers more precision in describing their experimental treatments. They will be able to indicate which of a medium's capabilities are employed, rather than lumping all uses of a particular medium together. It will also give instructional designers and faculty members a menu of tools from which they can draw to fashion solutions to particular educational problems.

Symbol systems

Media may differ in the symbol systems they are capable of employing. Television can employ visual representational symbol systems, for example, radio cannot. According to Salomon (1974, 1979), different symbol systems require learners to invest different amounts and kinds of mental processing. Symbol systems can be related to cognitive processes, and therefore to learning, in three ways. First, symbol systems can be more or less well suited to convey different types of information. For example, if subtle color-related information is to be communicated, it may be preferable to use visual means rather than verbal. Secondly, a message given in a particular symbol system may be more or less isomorphic with internal representations, depending on the learner, task, and content. The effects of different symbol systems on learning are probably mediated by the degree of novelty of the information being transmitted. Knowledge that has been gathered and stored over an extended period is less likely to be symbol system-dependent because it has been repeatedly accessed and reprocessed. New information that is unrelated to such well-established knowledge is likely to be more symbol-specific. Third, symbol systems may vary with respect to the kinds of mental processes needed to render them useful. "Reading" music requires different cognitive skills than "reading" text and this, in turn, requires different skills than it takes to understand the same words spoken.

A symbol system is constituted by a set of elements related to each other by syntactic rules or conventions and correlated in specifiable ways to fields of reference (Salomon, 1979; Goodman, 1976). All symbol systems can vary according to their "density" or notationality. Systems that are more notational have a close correlation between discrete elements and their referents. "They are syntactically articulate because they have readily identifiable and discrete inscriptions, and they are semantically unambiguous with regard to their referents" (Salomon, 1979, pp. 132-133). Non-notational systems have elements that are not discrete from one another and whose relations to their referents are ambiguous.

A particularly useful and straightforward criteria for distinguishing among symbol systems is by the sensory system or systems which they stimulate. Virtually all symbol systems used in instruction stimulate the visual or auditory sensory systems, (though the notable exception of braille demonstrates a symbol system that stimulates the tactile senses). Within each sensory mode, further differentiation can be made. Visual symbol systems can be differentiated into four smaller categories:

- Visual linguistic symbol systems are readable texts used to communicate information. Such symbol systems are of moderate notationality.

- Visual notational symbol systems would include musical, statistical, chemical, and other technical notation. As their name implies, these symbols are highly notational, syntactically articulate and semantically unambiguous.

- Visual signals include manipulations of light to draw attention or convey information to the user: flashing lights, differential use of colors, differential use of light intensities, etc.

- Representational symbols are graphic portrayals of objects, phenomena, or ideas. They differ according to whether or not they are meant to be accurate portrayals of their referents (pictorial representations) or merely signify their referents (iconic representations). Representational symbols also differ in their degree of notationality and in their animation (the degree to which they can show change, motion, or action).

Similar differentiations can be made among auditory symbol systems:

- Auditory linguistic symbol systems are equivalent to speech.

- Auditory signal symbol systems are changes in pitch or volume to convey information or direct attention.

- Auditory representational symbol systems are presentations of sounds that are "realistic." As with the analogous visual symbol system, auditory representational symbol systems can closely resemble their referents or merely signify them.

- Music. In visual symbol systems, we classified musical notation with other notation, such as chemical and statistical. Auditorially, music is a distinct symbol system, conveying information in ways different from signals, words, or representational sounds.

Control capabilities

Although capabilities to employ certain symbol systems make important distinctions among media, they do not sufficiently describe all the important distinctions. Media vary in their abilities to process information. The abilities of a medium to process information (symbol systems) in a variety of ways are the control capabilities of that medium. Control capabilities also require learners to invest different amounts and kinds of mental processing.

For example, books and computers both present visual symbol systems, typically text or representational symbols. Books present information, and a well written book can also assist the reader in processing the information by using headings, a table of contents, etc. But computers can present information in very controlled ways, determining the pace and the sequence of the presentation. Furthermore, the computer can process information **for** the learner (e.g., conduct computations) and receive, process, and store information **from** the learner. In a physics simulation, for example, the student specifies the direction and force imparted to a billiard ball in a Newtonian world and the computer displays, in real time, the change in velocity and direction as the ball impacts a surface. Simultaneously, perhaps in another window, a graph can chart the velocity of the ball over time. These are processes of which a book is not capable. A specific instance (or even several instances) of this phenomena could be displayed in a diagram in a book, and a large number of instances could be represented in look-up tables, or perhaps the formula could be given for the student to use in computing the results of a specific instance of choice; but these clearly involve different symbol systems and require different cognitive skills and knowledge. The knowledge may not correspond to a particular learner's representation of the phenomena and the skills may not be in a learner's repertoire, or a student may not be motivated to use them. The control capabilities of the computer that are employed in this simulation may engage a learner's interest by giving him or her control over the direction and force imparted to the ball, and it may aid the learner in transforming familiar knowledge (i.e., the behavior of a billiard ball) into previously unfamiliar knowledge about its velocity relative to its force and to its reaction with other objects. This can, in turn, aid in the understanding of this relationship as it is expressed in a formula, using yet another symbol system.

The capabilities of media to process information correspond to the way people process information, so the categories of control capabilities will sound familiar to those familiar with cognitive psychology: input/output, processing, and management.

Input/output describes a medium's ability to present and retrieve, and receive and store information.

- Presentation is the ability of a medium to display information to a learner in one or more symbol systems. All media have the capability of presentation, though they vary, as mentioned, in the symbol systems they can present.

- Retrieval is the ability of the medium to selectively locate stored information that is presented to the learner. Information can be retrieved from most media, but media vary in the extent to which they can participate or facilitate the process. Retrieving information from a reference book relies on a considerable amount of cognitive skill on the part of the user, the natural language inquiry of a computer data base, less so.

- Reception refers to the ability of a medium to receive information, or input, from a learner. This input may take a variety of forms and draw from various symbol systems, depending on the medium.

- Storage refers to the ability of the medium to provide an organizational structure to the information that it receives. Most media have information stored in them (although a telephone, for example, does not), but media vary considerably in their capabilities to organize the information.

Processing of information is the various operations the media may make on newly received or previously stored data. An incomplete list of these processes include: organizing (i.e., the structuring of information within a symbol system), translation (i.e., conversion from one symbol system to a parallel system; e.g., translation from English to Russian), transforming (i.e., the conversion across symbol systems; transformation from numeric information to graphic information), and integrating (i.e., combining information within or across symbol systems).

Management of information refers to a medium's ability to "make decisions." These are higher-level operations that monitor the processing of information, alter it, modify it, and correct it based on interactions with the environment. There is a recursive nature to this. This capability also includes the alteration, modification, and correction of the management process.

As with symbol systems, a medium's control capabilities are not always used in every instructional presentation. The profile of these for a specific medium defines a range of possibilities for instruction; the instructional designer must select the media attributes most appropriate for some specified purpose.

It should be said that there is no reason to think that media with more control capabilities are necessarily more instructionally effective. Much depends on the requirements of the instructional context: the learners, tasks, and situations addressed. Given some educational purposes and some types of students, media with fewer control capabilities may be sufficient compared to others with more. But media with processing and management capabilities may be able to meet the requirements of some tasks and learners that others cannot. Figure 4 extends the parallels drawn in Figure 3 to show how media capabilities correspond to certain task requirements and learner capabilities. But the role that the medium plays in this regard rests with the method selected.

Methods

Media can be defined in terms that correspond to cognitive processes in the learner, but as Clark points out (1983) there is nothing inherent in a medium that assure its cognitive effects. Which medium is used in a specific design, which of its symbol systems and control capabilities are employed is a function of the method used, that is the cognitive role it will play in learning.

Methods vary in their intrusiveness, learner control, and the cognitive load they relieve of the learner. Salomon (1979) and others (Corno & Mandinach, 1983; Corno & Snow, 1986) describe a range of instructional methods from those that short-circuit cognitive functions, to those that model, to those that activate cognitions. Methods that short-circuit cognitions are those that compensate for a learner's weakness by performing cognitions that a learner is unable or unwilling to perform alone. Methods that model

	Learner Aptitudes	Learning Tasks	Media Capabilities
	Visual/Spatial Ability		Symbol Systems
	Crystalized Ability	Verbal Knowledge	Input/Output
Cognitive		Intellectual Skills	Processing
	Fluid Ability		
		Cognitive Strategies	Management
Conative	Metacognitive Strategies		
	Motivation		
Affective		Attitudes	
	Anxiety		
		Psychomotor Skills	

Figure 4. Parallels between learner aptitudes, tasks, and media control capabilities.

are those that remediate missing skills. Methods that activate do so by cueing the learner to use skills that are already in their repertoire and thus capitalize on learner strengths. Methods that short-circuit are most intrusive, those that activate are least. The instruction controls the learner's cognitions with methods that short-circuit, and cognitions are under the control of the learner with methods that activate.

Corno and Snow (1986, p.621) refer to the flexible and full use of this continuum in their definition of adaptive instruction:

> Adaptive teaching is teaching that arranges environmental conditions to fit learner individual differences. As learners gain in aptitude through experience with respect to the instructional goals at hand, such teaching adapts by becoming less intrusive. Less intrusion, less teacher or instructional mediation, increases the learner's information processing and/or behavioral burdens, and with this the need for more learner self-regulation. As the learner adapts, so also must the teacher.

Recall that Gagné (1985) identifies a list of cognitive events that are essential for learning: attention, selective perception, rehearsal, semantic encoding, retrieval, response organization, feedback, and executive control process (processes that activate and modify the above events). It is important to note that, although Gagné contends that all the learning events must occur for learning to be successful, the events need not be performed by the learner. Some learners for some tasks can and will perform these cognitions on their own. Indeed, Corno and Mandinach (1983) define a "self-regulated learner" as one who does so. On the other hand, some learners may lack these cognitive skills, the control processes to activate and regulate them, or the motivation to use them; in which case, the events may be performed by the instruction.

Short-circuiting

Gagné and Briggs (1979) generate a list of instructional events that have a direct correspondence to cognitive events listed above. Designs that incorporate these events will take on the cognitive load for the learner. The instruction directs the cognitions of the learner and preempts the need for metacognitions. In effect the instruction "learns" for the student. As a result, learners engage in cognitive rather than metacognitive activity (a pattern termed "recipience" by Corno and Mandinach) and the method should be used carefully. The nine events in Gagné and Briggs' list form the components of short-circuiting methods and they are:

- Gaining attention. The instruction evokes and maintains the learner's engagement in the task. Through the use of a change in stimulus (movement or sound), the instruction can capture or direct the learner's attention.

- Informing the learner of the objectives. The instruction can set the goal for the learner and use it as a reference for progress and performance.

- Stimulating recall of prior learning. Previously learned information and skills needed for understanding the new task can be brought into the learner's short-term memory.

- Presenting stimuli. The instruction presents the stimuli related to the task in the form that will be used in the assessment.

- Providing guidance. The task can be performed or demonstrated for the learner. The form of the guidance will depend on the nature of the task. Facts are stated, concepts defined and examples provided, rules are applied.

- Eliciting performance. The learner is asked to perform the task in the same manner as it was presented during guidance.

- Providing feedback. The instruction will give the learner information on the correctness or the nature of the incorrectness of the performance.

- Assessing performance. The new skill is performed several times to assure that it is appropriately generalized.

- Enhancing retention and transfer. The skill is performed on several occasions and in various situations to assure that the skill will be retained and can be transferred to other appropriate situations.

This very structured approach to instruction is commonly associated with programmed self-instructional materials. Gagné, Wager, & Rojas (1981) illustrate the application of these events to computer-assisted instructional tutorials.

Research suggests a strong interaction between this approach and certain learner aptitudes. The short-circuiting method is effective in some situations and counter-productive in others. Tobias (1981) summarized several of his studies to demonstrate the inverse relationship between intensive instructional support and prior knowledge. Highly organized instruction that elicits student responses and provides feedback is most effective for novice learners, those with little prior knowledge in a subject domain. Peterson (1976) found that a highly structured approach was most effective for students who scored high on a personality factor called "conformity." It was ineffective for students who scored high in "independence." Snow and Lohman (1984) conclude that for low ability learners, instructional treatment should be made explicit, direct, and structured so as to provide the initial skills and knowledge that will be necessary for subsequent learning. At the same time, these students should receive training that would develop their learning strategies and skills. On the other hand, short-circuiting may actually conflict with mental structures and processes of high ability learners and interfere with their learning.

The short-circuiting of cognitions can also affect motivation. Even though the learner is successful, he or she may attribute the accomplishment to the instruction or the ease of the task rather than to self. At best self-efficacy will increase for a narrow range of tasks with this approach (Corno & Mandinach, 1983).

On the other hand, instruction may short-circuit motivation directly. When the learner lacks interest in the task to be learned it may be necessary to short-circuit motivation by providing motivation externally. Providing rewards or other inducements to engage in learning performs this function. Competition, cooperation, and social recognition are motivational embellishments that if exogenous to the learning task serve to deemphasize learner motivation. Whereas supplying external motivation may be necessary on occasion, there are problems created or unresolved by this approach (Csikszentmihalyi, 1978). In a situation of limited resources, extrinsic rewards can only be administered sparingly. Recipients of extrinsic rewards can become quickly satiated. Most importantly, they can attribute their behavior to the influence of the reward or external conditions rather than to their own interests. This makes it less likely that future learning will occur in the absence of such external conditions (Lepper and Green, 1978).

There also seems to be an interaction between method and learning task. Peterson (1979) reviewed several studies in K-12 settings which examined short-circuiting, what she referred to as direct instruction. While these studies showed that this method is effective for student achievement of lower-level cognitive tasks, more open approaches were better for increasing students' creativity, independence, curiosity, and favorable attitudes toward school and learning. This has important implications for higher education, where goals include higher-level cognitive tasks, self-regulation, and motivation.

In summary, it is clear that the highly structured method of short-circuiting student cognitions and motivations has a potentially important but very circumscribed role in college education. This approach to instruction should be used, at least initially, with students who are at risk. Students who score low on standardized achievement tests, or who have little prior knowledge in a subject domain, as well as those students who have a need to conform, can benefit from this approach. Corno and Mandinach (1983) conclude that short-circuiting would be useful for accomplishing immediate lower-level objectives and for increasing task-specific efficacy expectations in lower ability students.

Its use should be limited in duration (perhaps the first few semesters in college or the first few weeks in a course) and emphasis should be placed on developing skills that will foster independence in the learner.

Modeling

Corno and Mandinach (1983) identify "participant modeling" as the method most appropriate to building self-regulated learners. Self-regulated learners are those who are actively engaged in the acquisition and transformation of information needed to learn. Whereas short-circuiting methods perform these processes for learners that are unskilled in them, modeling involves learners in acquiring these skills. In effect, it seeks to remediate their deficiencies. With this approach mental processes are demonstrated and the learner is gradually made to practice or undertake the process on his or her own. A significant cognitive load is retained by the learner, but the instruction provides some support and guidance. The learner is guided in the meta-cognitive aspects of the task while left in control of the cognitive elements.

Tennyson and his colleagues (Tennyson 1980, 1981; Tennyson & Buttrey 1980; Johansen & Tennyson 1983) have examined the use of this guidance in computer environments. Students who are given progress reports and individualized advise on appropriate instructional strategies (on the amount and sequence of instruction) and yet are left to follow the advice or not, took less time and did as well on the posttest as a second group whose instruction was computer controlled. They also did better than a third group that had control of their instruction but did not receive progress reports or advisement. More importantly, the advisement group also demonstrated that they were able to make increasingly better self-assessments and management decisions during subsequent instruction.

Corno and Mandinach (1983) contend that in addition to developing cognitive skills, this method is likely to increase self efficacy by increasing the cognitive engagement of the learner, which, in turn, evokes attributions to personal control. Motivational cognitions can also be directly guided. Attributional guidance consists of statements and feedback designed to encourage learners to make attributions about self and strategies that facilitate learning (Bandura, 1977; Schunk, 1981).

As with other treatments, modeling interacts with learner aptitudes. For higher ability learners, those already having skills in acquisition and transformation processes, modeling may reduce learning speed and interfere with their learning (Salomon 1979). Nonetheless, it may be useful in the long run even for these students. Modeling may add to the repertoire of strategies that these students have available to them (Corno & Mandinach, 1983).

Activating

The self-regulated learner has the meta-cognitive strategies and cognitive skills to assemble and transform information and monitor progress. If any intervention is needed at all for these learners, it may be sufficient to give them the tools and resources that they need and that activate the learning process that they have mastered.

The activating environment is designed in such a way as to elicit or evoke certain cognitive activities. Much like a hammer elicits pounding or a restaurant elicits food ordering, an activating educational environment has tools and resources that have been carefully selected or designed to elicit a certain range of cognitive behaviors and motivations. Such environments are consonant with discovery learning, inquiry, and open education and are commonly associated with independent study, practica, laboratories, and other exploratory instructional treatments.

Malone and Lepper (1987) identify several ways that such environments and instructional treatments can activate intrinsic motivations endogenous to the learning task. One technique is the use of fantasy. Fantasy evokes mental images of physical or social situations not actually present. Fantasies can be very emotionally involving and their potency is greatest when they address emotional needs of the user. In intrinsic fantasy, problems are presented to the learner in terms of the fantasy so that acting within the fantasy is roughly synonymous with solving the problem. In extrinsic fantasy, the problem is not presented in terms of the fantasy, though the learner's performance on the problem affects events in the fantasy.

Intrinsic motivations can also be activated by stimulating curiosity. Curiosity is evoked when presentations are novel and surprising, but not incomprehensible or overwhelming. Malone distinguishes between two types of curiosity. The cognitively curious learner is motivated to alter cognitive structures to make them more complete, parsimonious, or consistent.

Challenge, like curiosity, requires an optimal level of stimulation, but challenge more fully involves a learner's self-esteem. An event is challenging when it provides goals whose attainment is uncertain. The challenging quality of an activity can be manipulated by variations in the level of uncertainty and changes in the goals themselves. The degree that an outcome is certain can be affected by varying the difficulty of the task, by revealing information necessary for the task only under specified conditions, or by introducing some random factor that will contribute to success or failure. The motivational strength of a goal can be influenced by ensuring that goals are personally meaningful and by providing feedback to learners about their goal-related performance.

It is worthwhile to reflect on possible effects of challenging designs on the self-esteem of learners. One would expect that success in challenging situations will make people feel better about themselves. However, failure in a challenging context can often result in diminished self-esteem. Much of the negative effects of challenge on self-esteem can be avoided by allowing the learner some control over aspects of both the goals and the uncertainty of their attainment. Emergent goals, goals that arise out of the interaction between a person and environment, are more motivating than fixed goals (goals that are predetermined by cultural convention). Opportunities for learners to generate their own goals in interaction with the learning tasks would enhance motivation.

Malone and Lepper (1987) also examine the motivational aspects of learner control. The motivational importance of learner control extends to most aspects of instruction. It is not always necessary for learners to have "real" control over instruction, only a sense of control, for their motivation to be enhanced. Learners can have real or perceived control over goals, pace, instructional events, branching, review, types of symbol systems, and other aspects. Perceived control requires that: 1. there be options from which the learner may choose, 2. the options have different values for the learner, and 3. learners believe that each option is contingent on an action of the learner. (Note that "automatic" branching sequences do not convey a sense of control. Though they are contingent on actions of the learner they are typically not chosen from a number of alternatives by the learner.)

Learners who are allowed some say in the progress of their education (or believe they have some say) will presumably have an expanded sense of competence and power. When students are not permitted choice or control in instruction, they are likely to assume a more passive, detached relation to the lesson and have a lower sense of their own power and competence. There is probably some optimal, intermediate number of choices that will be maximally motivating. Learners may be overwhelmed and unable to make effective choices in an environment that lacks any structure.

Both Snow (1980b) and Clark (1982) have demonstrated the problems inherent in learner control. It appears that students are frequently not very good at making accurate judgments about the amount of effort they will have to expend to achieve maximum learning outcomes. Low ability students typically report liking less structured methods, apparently because they allow them to maintain a "low profile" so that their failures are not visible. High ability students like more structured methods which they believe will make their efforts more efficient. As we will see below, these selections run contrary to the treatments that are likely to be most helpful for these students.

Activation is, of course, a very unintrusive approach which provides little or no instructional support and places a large cognitive burden on the learner. Thus it is not surprising that this method interacts with learner aptitudes. Activating approaches tend to be effective for higher ability learners, but ineffective or even detrimental for lower ability learners (Cronbach & Snow, 1977). High ability learners do especially well under instruction that is significantly incomplete because it demands and affords opportunities for the exercise of their idiosyncratic knowledge, skills, and strategies (Snow & Lohman, 1984). Methods that model or short-circuit interfere with these.

Dowaliby and Schumer (1973) and Domino (1974) found an interaction with an unstructured approach they termed "student-centered" and the personality trait anxiety. Students scoring low in anxiety learned more in the unstructured approach while those high in anxiety benefited more from the structured approach. Peterson (1976) and Porteus (1976) found a somewhat more complicated interaction. Both students scoring high in ability and anxiety as well as those scoring low in ability and anxiety did poorly in unstructured environments. Indeed, activation may produce anxiety and motivational deficits in lower ability students (Corno & Mandinach, 1983). It is likely that they would experience failure and consequently experience a loss of self-efficacy and negative attributions.

Thus, as desirable as the end state of self-regulated learner is, merely eliciting this response will not work for those that do not have the skills. The occasional and strategic use of short-circuiting methods coupled with modeling methods is likely to be the best approach for these students.

III. A Taxonomy of Educational Computing Designs

Even the most casual survey of instructional resources on any campus would show that a variety of media are currently available and being used. Overhead transparencies, slides, films, and television are frequently used by one faculty member or another in one course or another, perhaps more frequently than computers are presently being used. Some of these applications are making an important contribution to the quality of education. Why should the NCRIPTAL program on Learning, Teaching, and Technology limit its focus to the educational application of computers?

We have established the fact that the number of microcomputers in higher education is already substantial and very likely to get much larger in the next few years (Riccobono, 1986). The allocation of resources that this represents and the need for information to apply these resources wisely may be sufficient reason to focus our research on the impact of computers. But the rise in popularity of particular media has frequently been used to justify research and has, correspondingly, given rise to charges that faddism drives the research agenda in instructional technology.

In this section we identify important conceptual and theoretical grounds for focusing our research on computers by contrasting the capabilities of computers with those of other media and discussing their implications for learning. We build a taxonomy of educational software designs based on the different instructional roles they play in learner cognition and on the computer capabilities they employ. The categories represent distinctive profiles of attributes that functionally correspond to different profiles of learners, tasks, and situations. For each category we identify the range of learner, task, and situation characteristics to which the design might best be matched. It is important to note, however, that these are not conclusions drawn from extensive research on computer applications, but they are tentative hypotheses suggested by theory and initial research. Indeed, we conclude this section by specifying the portion of this domain that we will examine over the next four years. We identify the designs, contexts, and the hypotheses that relate them that will serve as our research agenda.

7. Computer Capabilities

There seems to be general consensus that the computer is a powerful medium. But what does this mean? Are there characteristics of computers that, as a group, are unique among media? And if the computer's attributes are unique, how do they correspond to cognition and what are their implications for learning?

The answer to these questions is not simple because the "computer" is not monolithic. To a certain extent, attributes vary with different makes, models, and options. The characteristics of an IBM PC are different without and with a graphics board. There are differences between IBM PCs and IBM ATs. There are differences between IBM PCs and Apple Macintoshes, between Apple Macintoshes and advanced function workstations such as Suns, Apollos, and IBM RTs, and there are differences between these workstations and a Cray. There are differences between the computers that were available ten years ago, those that are available now, and those that will be available next year and in the next decade. However, acknowledging the diversity and changeability of human artifacts, it may still be useful to talk about the attributes of computers that are now "typically" available to college students and note exceptions where appropriate.

One of the important capabilities of computers is the range of symbol systems that they can employ. Historically, computers were initially limited to highly notational, unambiguous symbol systems, primarily numerical systems (such as machine language code). Thus mathematical, musical, and other technical notation systems are easy for the computer to handle. Over time, more advanced programming languages were developed. They were still highly notational but they began to approximate visual linguistic symbol systems (written text) in their less ambiguous aspects. More recent developments, in the memory size of computers, have accommodated various layers of translators which allow the user to communicate in a more natural language. Thus, "expert systems" written in LISP, Prolog, or one of the expert system shells allow users to make natural language inquiries of limited-domain data bases, such as medical diagnoses or airline schedules. Continuing developments in this area will accommodate the more ambiguous aspects of linguistic symbol systems in the near future. Additional hardware and software developments have allowed for speech recognition and production (audio linguistic symbol systems), but currently this capability is limited and not generally available. For example, current, affordable speech recognition capability is limited to 1500 words and must be "trained" for each specific user. Apart from these developments in "understanding" or processing linguistic symbol systems, the computer can currently store and retrieve, present and receive textual linguistic symbol systems in their full diversity and ambiguity without further processing. In this way computers are like books, and if this is the only capability of the computer that is used, the phrase "electronic page turner" is warranted.

Perhaps the greatest advance in computer symbol system capabilities has been the ability to present representational symbol systems. This includes graphs, charts, maps and line drawings. Thus, students can see the animated molecular reaction of chemical reagents or the erosion of the Grand Canyon over the ages. But, except for the advanced function workstations, these symbol systems remain more iconic than pictorial and animation is fairly limited. With appropriate peripheral devices, such as touch screens, light pens, and graphics tablets, the computer can also receive, store, and process (in a limited way) representational information, primarily location. Thus, a student can point to a particular body part of a depicted insect or the position on a map of a major military engagement.

Many of the computers commonly available can also present non-linguistic, auditory symbol systems. These include signal systems that emphasize components of the visual presentation and are associated with correct or incorrect student answers. The presentation of music is also a capability with these systems.

Thus the computer is among the most powerful media in the symbol systems it can handle. It is not distinguished by the particular symbol systems that it employs, for all of its symbol systems are available through some other medium. Nor is it distinctive in the quality of its symbol systems, for even slides and texts with pictures, for example, are currently better in presenting pictorial symbol systems (animation aside). The computer is distinguishable more by the range of symbol systems at its disposal. In this regard, it approaches television (and film), which remains the most comprehensive symbol system medium. However, with the capability to interface with videotape and videodisc players the computer can incorporate the richness of this medium, though the necessary equipment is still not typically available in higher education (Riccobono, 1986).

But as comprehensive as the computer is in the range of symbol systems it can employ, it is most distinguishable from other media in its control capabilities, primarily processing and management capabilities. As with all media, a computer presents or displays information. However, the pace and sequencing of the presentation can be more under the control of the learner than with broadcast television and more under the control of the instruction than with a book. Also, as with most media the computer can receive and store information, although the computer, via the software, can have more control over the structure of the storage of information that it receives than is possible with other media. Even though the computer shares the capability to store and present information with other media it can do this in "real time" and thus it is able to interact with the user. Salomon (1986a) defines interaction in terms of the interdependence and mutuality of behavior and understanding such that the adjustment of communication of each party is based on previous communication. Even though computers are still limited in this they can make some adjustments in the information they present based on the information they receive in ways other media cannot. Salomon contends that this capability is important in maintaining the cognitive engagement, or "mindfulness", of the learner and thus facilitates learning.

Unlike other media, the computer has the ability to process information that it receives, stores, retrieves, and presents. Unlike any other media the computer can take this information and transform, translate, calculate, sort, order, integrate, and infer. Thus, a computer can receive the notation of a musical score and transform this into audio music, or it can receive numerical values for a physics equation that drives an animated pictorial representation of a phenomenon. The computer can also manage information; it can monitor, regulate, and modify these processes, evoking one or the other based on the nature of the interaction with the learner. Thus, a computer can modify its instruction based on its diagnosis of the errors of an individual student (Burton & Brown, 1982) or as a result of testing instructional hypotheses over a group of students (O'Shea, 1982). Alternatively, the computer can advise students on their selection of instructional strategies based on their performance (Tennyson, 1980). Whereas these capabilities are not yet fully developed or commonly available, this is the primary emphasis of the artificial intelligence efforts that promise to dramatically increase the power of computers in the near future.

The computer is an important object of study not only because of the range of its symbol systems and because of its unique control capabilities, but because these attributes are so isomorphic with the representations and processes involved in human learning (as illustrated in Figure 4). Because of this parallelism and because of the capability of either learner or instructional control, the computer can employ a range of methods to accommodate learner aptitudes. The computer can short-circuit by taking on a large amount of the information processing burden of the learner. It can model processes, or it can activate or amplify the learner's own process. Also, the computer can accommodate a range of tasks. It can patiently tutor verbal knowledge, it can dynamically model intellectual skills, and it can model, activate, or amplify cognitive strategies. It is this last possibility that holds the most promise, for learners may internalize the very processes in which the computer excels and thus become better learners.

A number of theorists (Bruner, 1966; Olson, 1976, 1985; Pea, 1985; Perkins, 1985; Vygotsky, 1978) take the position that intelligence is not a quality of the mind alone, but a product of the relationship between mental structures and processes and the tools of the intellect provided by the culture, including media. Olson (1976) illustrates this in his examination of the historical impact of the book on intellectual development. He contends that the move from oral to print technology changed language from an ephemeral means of communication to a permanent, visible object, the written word. "With literacy, the function of memory has been altered from an exclusive concern with preservation of content to a concern with organization and retrievability." (Olson, 1985, p.7) Correspondingly, the processing and management capabilities of the computer may extend this function to planned mental action. Perkins (1985) suggests that while the written word helped extend the reach of thought by helping us to circumvent low-level limitations of human short-term memory, computers may further extend it by circumventing low-level limitations in processing ability. This extension of thought is what Perkins refers to as a "second-order finger tip effect."

Pea (1985) makes a similar distinction between the abilities of the computer to amplify cognition and to reorganize these processes. By amplifying cognition, Pea means that computers may help us do things that we already do more effectively or efficiently. On the other hand, he contends that the use of the processing capabilities of the computer, with such software as spreadsheets, problem solvers, and planners, can restructure thinking activates and make them explicit such that users come to discover new methods of thinking and internalize these.

But this internalization does not automatically result from using computers or even the more unique capabilities of computers. As Salomon (1986a, 1986b) points out, this internalization can result from either "low road" or "high road" transfer. Low road transfer results from repeated practice in a variety of situations and can lead to near automatic, "mindless" application of the processes in new situations, primarily under the control of the stimulus. With high road transfer, the individual mindfully abstracts the essential process and decontextualizes it. This mindfulness is determined in part by the learner's proclivities and in part by the nature of the materials—the design.

Thus our interest in studying instructional computing stems from the capabilities of computers, both the range of symbol systems that they can employ and their unique control capabilities, and the concomitant potential that computers can be used for a broad range of tasks, learners, and situations in higher education. But especially, we are interested in the extent to which these capabilities correspond to the advanced cognitive skills and abilities most desired as outcomes of higher education, and the extent to which these processes can be internalized through appropriately designed computer software.

8. Categories of Instructional Computer Software Designs

Taylor (1980) offers an informal scheme for classifying educational software as tutors, tools, or tutees. The distinctions between these types of software rest primarily on attributional criteria, certain features of the software's operation. So, for example, tutorial software is defined in this way: "The computer presents some subject material, the student responds, the computer evaluates the response, and from the results of the evaluation, determines what to present next" (p. 3). To be a tool the computer "...need only have some useful capability programmed into it" (p. 3).

A tutee, however, is defined in terms of its relationship to the learner, its presumed effect on the learner's thinking. Through programming, a student is in effect tutoring the computer (i.e., the tutee) to perform some task. In the course of doing this, the student learns the task herself and also gains insights into her own thinking. Taylor then identifies the features or capabilities of the computer that enable this relationship: its dumbness, it patience, its rigidity, and its capacity for being initialized so as to start over from scratch.

It is this second, relational approach to criteria that we would like to use to extend and formalize these categories to form a taxonomy of instructional software designs. Using principles of modern taxonomy, we define the categories in terms of relationships rather than attributes. In this case, the relationship is the role the software plays in the cognitive functioning of the learner. The categories are then associated with attributes of the software and the capabilities of the computer that they employ to manifest this relationship.

Basing the classifications on cognitive functioning provides a unifying theme across categories, and between categories of computer software and other types of instructional interventions. It also provides a means of appropriately matching types of software with particular learners, tasks, and situations (also described in terms of cognitive processing). Finally, this foundation provides a theoretical basis that facilitates hypothesis generation and research.

To Taylor's classifications, we have added guided simulations. We have also extended the definition of the tutee category and retitled it exploratory environments (of which tutees are one kind). Tutorial, guided simulation, exploratory environment, and cognitive tool correspond to the primary method used or role they play in learning. Thus they differ in the amount of structure, intrusiveness, learner control, and in their relief of cognitive load. Tutorials and unguided cognitive tools anchor the two extremes of instructional computing, the former being structured to great detail, the latter being almost entirely unstructured. Simulations, exploratory environments, and guided tools are intermediate forms of instructional computing mixing elements of program- and learner-control. As they differ in methodology, the types of software also differ in their characteristics, or the capabilities of the computer that they employ, and these are described. We also describe the type of instructional context for which the software might be best matched. Because of the conceptual underdevelopment of situations, contexts are only addressed by learner and task characteristics.

In addition to these four categories of software we have constructed three other *components* that may be incorporated into any type of software for specialized purposes. These include: a motivation component, a graphic component, and a user interface component. It is important to note that these categories and components are not necessarily comprehensive. Other designs and modifications may, and likely will, emerge as research in this area progresses.

Tutorials

Tutorial programs are the instructional interventions that allocate the greatest control to the program. They provide the most structure and guidance to the learner. Tutorials use much of the computer's control capabilities to take on a large portion of the cognitive load during learning and they short-circuit much of the learner's meta-cognition. Complete tutorials provide all of the instructional events described by Gagné (Gagné & Briggs, 1979; Gagné, Wager, & Rojas, 1981). Thus, the program sets the goal for the learner, reviews relevant prerequisite information, presents the stimulus, provides guidance, requires a response, gives feedback, and so on. An example of this structure can be seen in Figure 5.

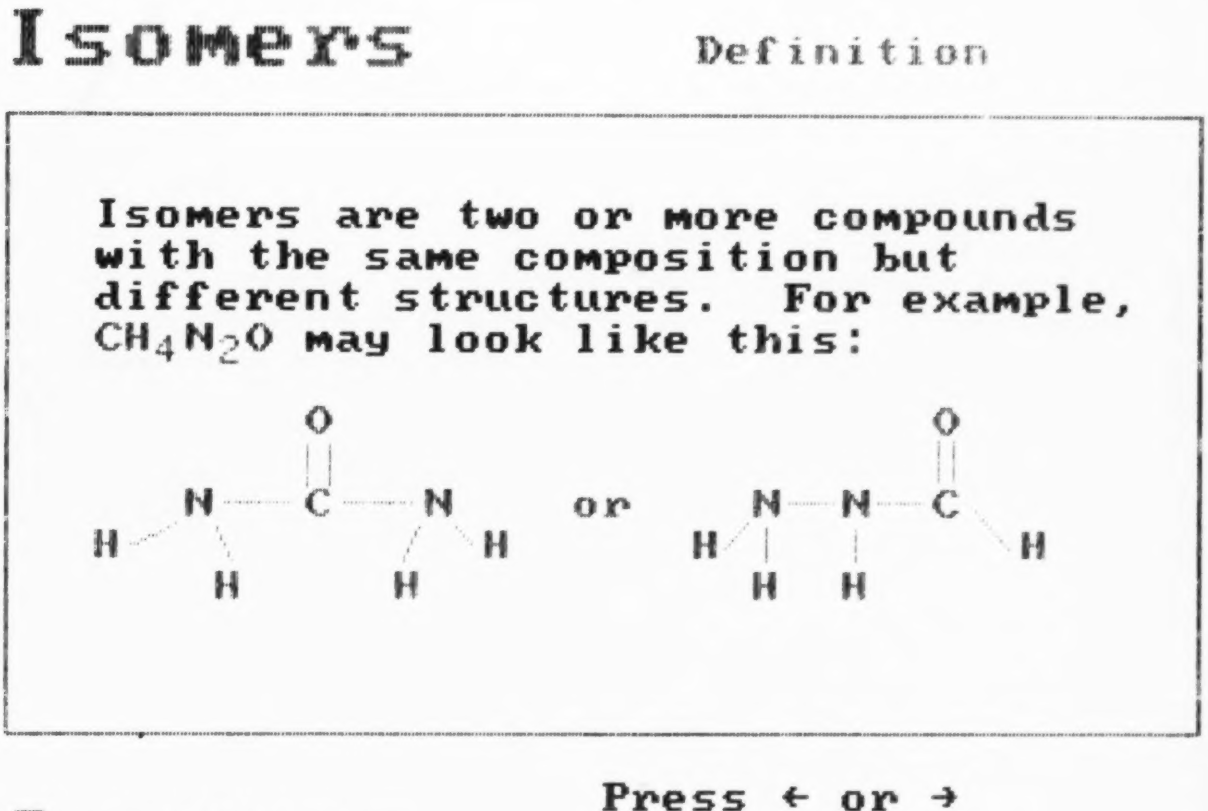
With simulations, exploratory environments, and cognitive tools many of these control functions are performed by the learners themselves. Incomplete tutorial packages rely on other sources of instruction. Indeed, a common application of the computer in education has been for drill-and-practice exercises. Such software involves a subset of Gagné's events (assessing performance and enhancing retention and transfer) and yet it assumes the remaining instructional events are supplied for the learner by some other source (perhaps a lecture or textbook reading). Thus for our purposes, drill-and-practice software is included as a component of tutorial software rather than as a distinct category of its own.

By defining tutorial software in terms of the instructional support provided by Gagné's events, specific comparisons can be made with more traditional tutorial forms such as programmed texts. Most current tutorial software differs little from tutorial text in that the distinct capabilities of the computer are rarely used. Perhaps this is why computer-based instruction has had effect sizes similar to programmed instruction in Kulik's meta-analysis (Kulik & Kulik, 1985). Using the more distinctive capabilities of computers may allow for more powerful effects within the tutorial model. One example of this is the nature of the feedback provided to the learner. Because of the limited control capabilities of text the feedback is commonly "prototypic;" that is, the correct answer is given (in the next frame or on the next page) and the learners are left to compare it with the answer they gave and to make some assessment of correctness. On the other hand, the computer can process short, text-based responses and actually evaluate the answer to provide not only information on its correctness but comments on the nature of any incorrect answers (although it is still limited in this regard).

The management capabilities of the computer allow for the branching of students to instruction tailored to their errors. Indeed, it is the use of the management capabilities of computers that creates the most distinctive form of tutorial, what is coming to be known as intelligent computer assisted instruction (ICAI) or intelligent tutoring (Sleeman & Brown, 1982). Tutorial software can be designed to build a representation of the learner's current understanding of the domain, and thus can recall and build on prerequisite skills in a very precise manner. The guidance can also be very precise in that the tutor or "coach" can supply information that corresponds to the specific misunderstanding of the learner. Such a sophisticated tutorial might monitor the performance of a student, keeping track of the student's rate of progress, number of correct responses to questions, and the type of questions that the student most frequently answers incorrectly. On the basis of the gathering information, the computer could direct the student to different parts of the content or present remedial reviews. The student could be completely unaware that he or she is systematically reviewing specially selected material, but this covert activity of the program is taking advantage of the computer's capabilities to store, organize, process and manage data.

Learners

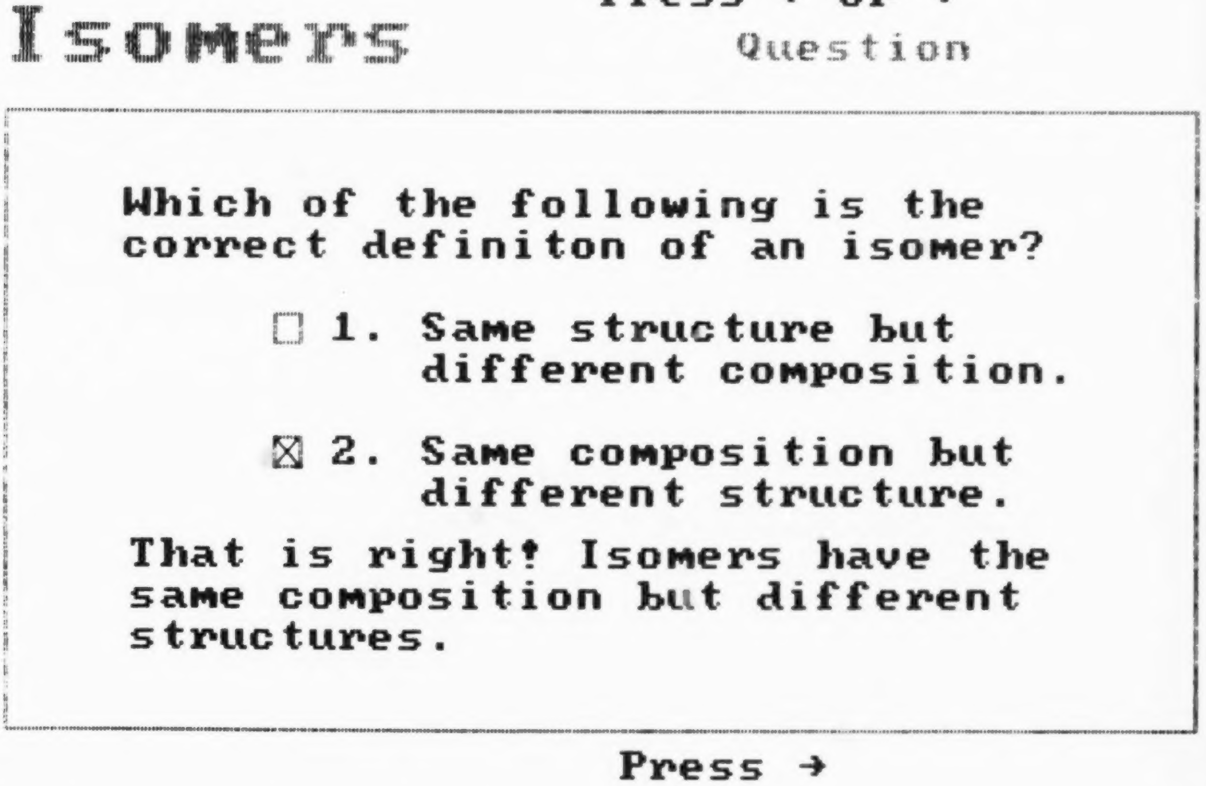
Providing structure in the form of these events has some distinct advantages for certain learners. Without opportunities or the need to determine outcomes, recall prerequisite skills, select the stimuli, etc. (these being provided by the instruction), the learner can entirely focus his or her attention on the information and on the explicit events as they are presented. The learner is not distracted by choices that have to do with instructional management and meta-cognition. Thus, given its high degree of structure, the computer tutorial is well suited for use with students who might otherwise not be able to acquire a specific body of knowledge because they lack the processing and managerial skills to successfully learn the subject matter on their own. This approach may also be useful for learners who are self-regulated but who are novice enough to a particular domain that



Isomers Definition

Isomers are two or more compounds with the same composition but different structures. For example, CH_4N_2O may look like this:

Press ← or →



Isomers Question

Which of the following is the correct definiton of an isomer?

☐ 1. Same structure but different composition.

☒ 2. Same composition but different structure.

That is right! Isomers have the same composition but different structures.

Press →

Figure 5. An example of a tutorial from a chemistry program.

the added demands of self-regulation are an undesirable burden (Corno & Mandinach, 1983).

It is important to note that such structured interventions may have their disadvantages for other learners. Less sophisticated tutorials force students to learn in ways that may or may not be most favorable to them; that is, they are presented content that is structured in the way that the software designer thought best rather than in a way that may more closely correspond to their current conceptualizations. Other students may find tutorials difficult to learn from, not so much because the structure they present is inconsistent with their own internal structures, but because the programs are not motivating for them. For students who are able to be more self-directed in their education, the lack of opportunities to exercise these executive skills may be frustrating, especially if they think they can learn better using another method of their own choice. With few opportunities to control aspects of the tutorial, there are fewer opportunities to create emergent, idiosyncratic goals and to set a comfortable level of challenge.

Tasks

In a tutorial, the computer is made the expert in a given content area and systematically leads the learner through the material. These interventions are designed to increase a learner's declarative knowledge in a specified area. Even when the subject area is a procedure or intellectual skill, tutorials only provide information about the process, thus increasing the learners declarative knowledge about the process but not modeling or activating the skill.

Guided Simulations

The term "simulation" is commonly used to describe a wide range of experiences from physical mock-ups, such as wind tunnel experiments, to role plays and in-basket tasks. Graphic animation and motivational, game-like features are also commonly associated with simulations. But these could be components of tutorials or exploratory environments as well and thus they are not useful in distinguishing simulations. Indeed, for our purposes we extract the graphic and motivational components and address them separately for they serve other, specialized instructional functions.

We use the term simulation to refer to procedural systems that imitate real phenomena. However, this definition does not adequately distinguish between two subtle but importantly different instructional functions a simulation may serve. Those simulations that are primarily designed to functionally mimic procedural systems but provide minimal or no guidance for the mental operations needed to perform in the system we will call "exploratory environments." They will be discussed further in the next section. Those systems that mimic real phenomena and guide users through relevant cognitive processes we will call *guided simulations.*

To illustrate the difference, imagine two computer programs designed to simulate the micro-economics of running a business. In the first program, the student is given a small company and allowed to hire labor, invest capital, set prices, advertise and so forth, through iterative years. The student is given no guidance on how to make these decisions but is free to give a value for any or all of these variables and observe the results on profits. This kind of unguided simulation that primarily serves to provide consequential feedback within a procedural system we call an *exploratory environment.*

Now imagine the same program with the same symbolic business activities except, in addition, the student is asked either by the computer or an accompanying manual: "Do you have a hypothesis?" Depending on the student's responses, the computer may guide the student through the process of formulating a hypothesis, determining a design for testing the hypothesis, and collecting and interpreting data. This is the kind of support provided in the program *Biznes: A Simulation of a Firm* (Schenk, 1983). Figure 6 shows support provided by the manual and the results of a sample session. Notice that the program does not provide the hypotheses and experimental strategies nor does it state the relationships for the student as would a tutorial. Instead, the program models and

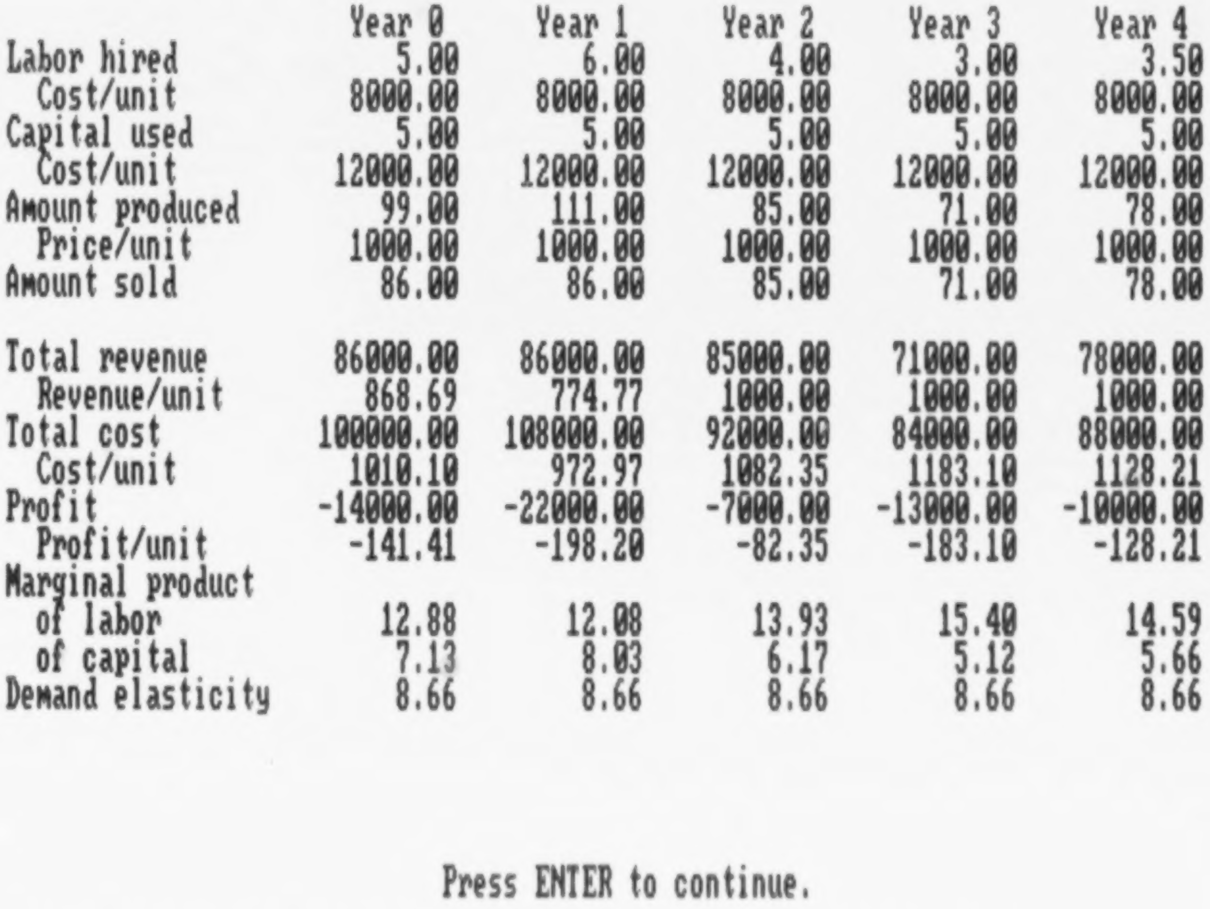
Fill in only one of the following two sentences:

I held capital constant at __________.

I held labor constant at __________.

If you are holding capital constant, write "labor" in the blank provided below. If you are holding labor constant, write "capital" in the blank.

Amount of ______	Output	Marginal Product	Total Cost	Approximate Marginal Cost (see note below)
0				
1				
2				
3				
4				
5				
6				



```
                       Year 0     Year 1     Year 2     Year 3     Year 4
Labor hired              5.00       6.00       4.00       3.00       3.50
  Cost/unit           8000.00    8000.00    8000.00    8000.00    8000.00
Capital used             5.00       5.00       5.00       5.00       5.00
  Cost/unit          12000.00   12000.00   12000.00   12000.00   12000.00
Amount produced         99.00     111.00      85.00      71.00      78.00
  Price/unit          1000.00    1000.00    1000.00    1000.00    1000.00
Amount sold             86.00      86.00      85.00      71.00      78.00

Total revenue        86000.00   86000.00   85000.00   71000.00   78000.00
  Revenue/unit         868.69     774.77    1000.00    1000.00    1000.00
Total cost          100000.00  108000.00   92000.00   84000.00   88000.00
  Cost/unit           1010.10     972.97    1082.35    1183.10    1128.21
Profit              -14000.00  -22000.00   -7000.00  -13000.00  -10000.00
  Profit/unit         -141.41    -198.20     -82.35    -183.10    -128.21
Marginal product
  of labor              12.88      12.08      13.93      15.40      14.59
  of capital             7.13       8.03       6.17       5.12       5.66
Demand elasticity        8.66       8.66       8.66       8.66       8.66


                    Press ENTER to continue.
```

Figure 6. An example of a guided simulation from the economics program and student manual entitled *Biznes*.

prompts the type of questions needed to infer the relationship from experience within the system.

Describing this type of simulation using Gagné's events, the most salient attribute is the provision of explicit guidance which corresponds to procedural nature of the task. However, we do not think of modeling as a passive process of mere observation. We define instructional modeling as participatory modeling (Corno & Mandinach, 1983); that is, the learner must in some way have opportunities to actively imitate or interact with processes represented by the model. Therefore, presenting stimuli, eliciting performance, and providing feedback are also important. The realism of a simulation is represented in these; each should be as realistic as possible using the symbolic capabilities of the medium. The feedback is typically not corrective or prototypical, but consequential. That is, the feedback comes in the form of resultant changes in the situation or stimuli embedded in the system that corresponds to ones the learner would encounter in the real situation. Other events in Gagné's list are not unimportant; indeed, all of them may be included in a guided simulation. Rather, guidance and realism in stimuli, performance, and feedback are the instructional supports provided by guided simulations while it may be assumed, at least for some tasks or learners, that the learners will provide their own objectives, prerequisite skills, etc.

Learners

Whereas Snow and Lohman (1984) identify those learners who are helped and hurt by the structure and support of the sort found in tutorials, their prescriptions address the two ends of the continuum of individual differences. Guided simulations provide a balance of program structure and learner control that addresses the middle group of learners. These are the learners who have the prerequisite knowledge and skills needed to approach the task but for whom enough discrepancy exists that the task presents a cognitive challenge. Students who have relevant cognitive skills but are not yet self-regulated learners or could benefit from the reduced cognitive load are best matched to the participant modeling methodology upon which guided simulations are based (Corno & Mandinach, 1983). Perhaps this represents an appropriate default methodology for young adult learners.

Tasks

Simulations, because they mimic real phenomena, are content-related and students who use a simulation can be expected to learn something about the imitated system. However, the primary instructional goal of a simulation is to teach cognitive processes to a learner by providing examples of how such processes operate. The program may model metacognitive activities or simpler intellectual skills. When modeling metacognitive activities, a computer simulation will show how to select a task, create strategies for accomplishing the task, and coordinate the various lower level cognitions involved in the task. The simulation may or may not perform some of the lower level cognitions (such as serving as a calculator when a subtask requires data manipulation). But in this case, the activities are ones that the learner is presumed to know and their execution by the learner would only distract him or her from observing and imitating the simulation's meta-cognitive activities.

On the other hand, simulations that teach intellectual skills may short circuit meta-cognitive skills, they may not model decisions regarding task analysis and strategy but make such decisions covertly. They will define the task and present simulating exercises for the learner in a program-controlled order. These are represented by the more structured, demonstration-like simulations where the task is tightly defined, a single variable is isolated, and the learner examines the effect on an outcome variable as the value of the isolated variable is changed.

Exploratory Environments

As mentioned above, exploratory environments are like simulations in that they are rule-based systems. The chief difference between simulations and exploratory environments is that the latter do not provide the kind of guidance that the former gives. (Exploratory environments can therefore also be called unguided simulations.) Rather, they provide resources to the learner and an environment that *activates* the learner's own cognitions. They may implicitly or explicitly prompt or structure certain performances but the learning activities are left up to the student to plan and execute. Learners have much more freedom to manipulate a phenomenon without advice or direction. Allowing the learner control over a range of functions is designed to activate a learner's planning, monitoring, and self-regulating skills, when these skills are present.

Exploratory environments are not instructional in the conventional sense of that word. They do not define an expected outcome, recall prerequisite skills, and systematically seek to produce that outcome in a given learner. Rather, the instructional designer assumes that any pedagogical structure that is applied to the user's activity will originate from the user, although a teacher or some other source of support may be needed if the learner fails to do so in a particular instance. In this regard, exploratory environments share their instructional function with cognitive tools, which are also designed to activate the cognitive and meta cognitive skills a learner already possesses.

There are two of Gagné's events that are performed in an exploratory environment, presenting the stimulus and providing feedback. The program presents salient features of the task environment. The software then uses the processing capabilities of the computer to restructure the situation in reaction to the learner's performance and according to the rule-based domain so as to provide the learner with consequential feedback. It is this feedback that can result in learning if the student has supplied the appropriate knowledge and skills to process it. Whereas feedback presumes a performance, it is not "elicited" nor is it guided. The performance, and any other learning activities, is initiated by the learner. An example of this is in Carolyn Lougee's *The Would-Be Gentleman* (1986). In Figure 7, the learner takes on the role of a bourgeois in seventeenth century French society. The learners can buy land, rent land, raise crops, advance in office, and so on. What they do, within the broad constraints of the simulation, is up to each. They then observe the impact of decisions on their social status and wealth.

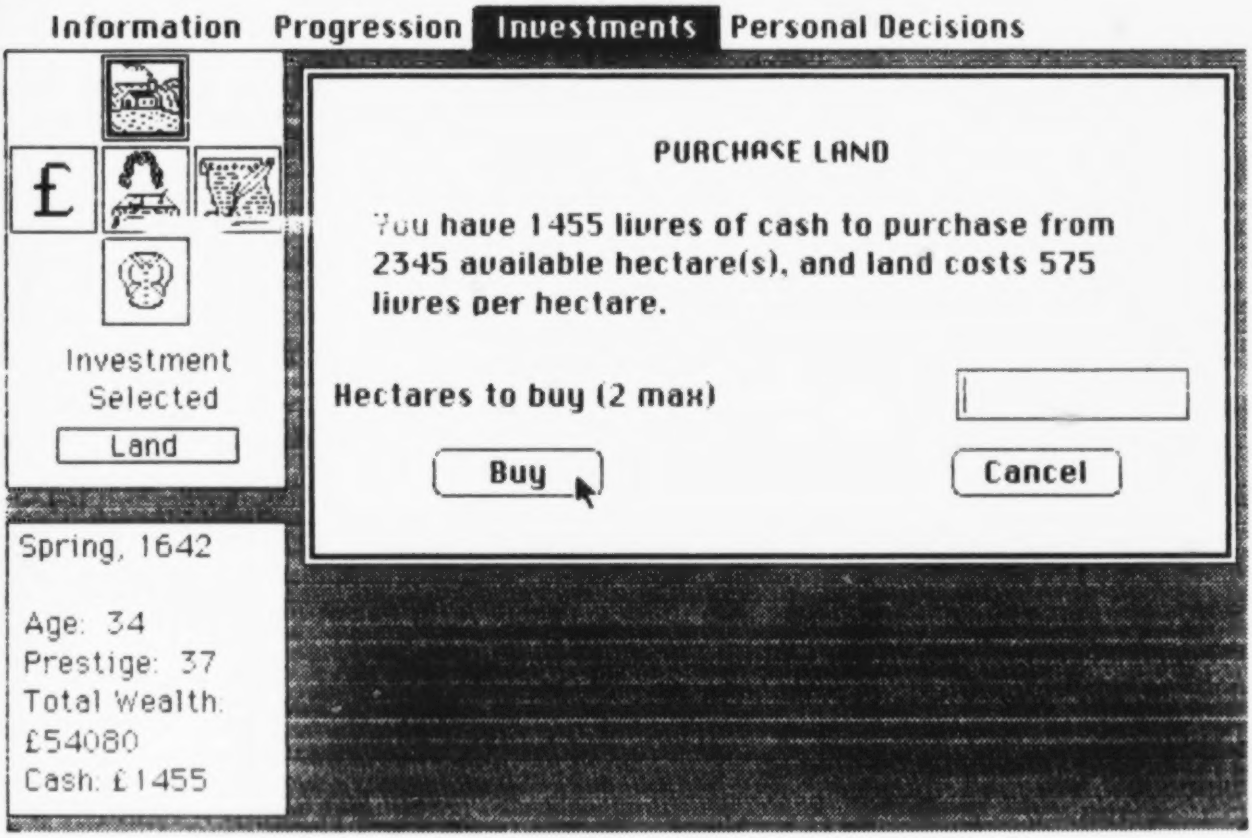
Learners

From what has been said so far about exploratory environments, it should be clear that their use puts greater claims on the abilities of students than do the more directive instructional interventions. This type of program is likely to prove most effective with students who have already developed sufficient meta-cognitive skills to monitor and adjust their own behavior (Snow & Lohman, 1984). Students who can create manageable and coherent instructional or learning strategies for themselves are likely to do especially well using an exploratory environment. Students with underdeveloped meta-cognitive skills or those who engage in tasks that overextend their cognitive resources may still find exploratory environments enjoyable to use because of the inherent motivational effects of learner control (Malone & Lepper, 1987). But the lack of guidance may reduce the likelihood of learning for these students.

Tasks

As with simulations, students may learn declarative and procedural knowledge about a particular domain from exploratory environments. However, it is more likely that learning will result only when learners bring with them vast amounts of this knowledge. This knowledge base would provide the learner with cognitive resources to structure the structure the environment, to infer rules and relationships, and build intellectual skills.

The unguided nature of exploratory environments makes them appropriate for learning metacognitive strategies. To facilitate transfer of these strategies, the environment to be explored may be quite artificial, rather than realistic, as long as it is based on the rules



Investment Selected: Land

PURCHASE LAND

You have 1455 livres of cash to purchase from 2345 available hectare(s), and land costs 575 livres per hectare.

Hectares to buy (2 max)

Spring, 1642

Age: 34
Prestige: 37
Total Wealth: £54080
Cash: £1455

Figure 7. An example of an exploratory environment from the history program entitled *The Would-Be Gentleman.*

or strategies to be learned. LOGO is intended to be such an environment. As a result of exploring an artificial environment the learner may abstract or decontextualize the rule so as to apply it in other settings, or, more importantly, perhaps learn the strategy of abstracting rules from their context.

Cognitive Tools

Generally speaking, tools are devices that amplify, extend, or enhance human capacities for work. Computers have been used as tools as long as there have been computers. Indeed the most common applications of computers are as tools for payroll, inventory, and word processing.

Cognitive tools are software programs that use the control capabilities of the computer to amplify, extend, or enhance human cognition. They are designed to aid users in task-relevant, cognitive components of a performance, such as revision in the writing of a composition or computation in the solution of physics problems, while leaving the performance open-ended and controlled by the learner.

Whereas the categories of tutorial, guided simulation, and exploratory environment are distinguished primarily by their characteristic methodology, cognitive tools do not have an exclusive methodology. Nonetheless, there are ways in which they may facilitate learning. In the least, they are designed to function by short-circuiting task-relevant, cognitive processes so as to reduce the cognitive load on the learner and free up cognitive resources that may be used for other, perhaps higher-level, cognitive processing.

Another way tools may facilitate learning is by defining or structuring the work space such that certain behaviors are more likely to occur. Thus they may activate learning-related skills and strategies in those students that have them. They are like exploratory environments in this way. The tool does not teach the skill it activates, but once activated the skill can be used in learning. The learner can use these activated skills in the self-regulated acquisition of other skills or new declarative knowledge. Such an example may be a common word processor. The ease with which a draft can be revised as a result of the word processor's "cut and paste" capabilities may increase the amount of revision, but the quality of revision and the final manuscript is likely to be determined by the skills the learner brings to the task.

A tool may also overtly display the processes it performs, thus providing the opportunity for some learners to internalize these processes (Salomon, 1986a). For example, there are several packages for writers, such as *Writer's Helper* (Wresh, 1985) and *HBJ Writer* (Friedman et al., 1986) that have features that assist learners to identify and formulate a topic, organize and reorganize their composition, and finally analyze and revise it. These correspond to processes identified by researchers (Flower & Hayes, 1980; Bereiter & Scarimalia, 1987) as ones used by effective writers. The program does not guide or model for the learner the development of a specific topic. Rather, it makes the process overt and thus provides the opportunity for internalization. Some tools, such as calculators, do not process information overtly and therefore are not candidates for internalization.

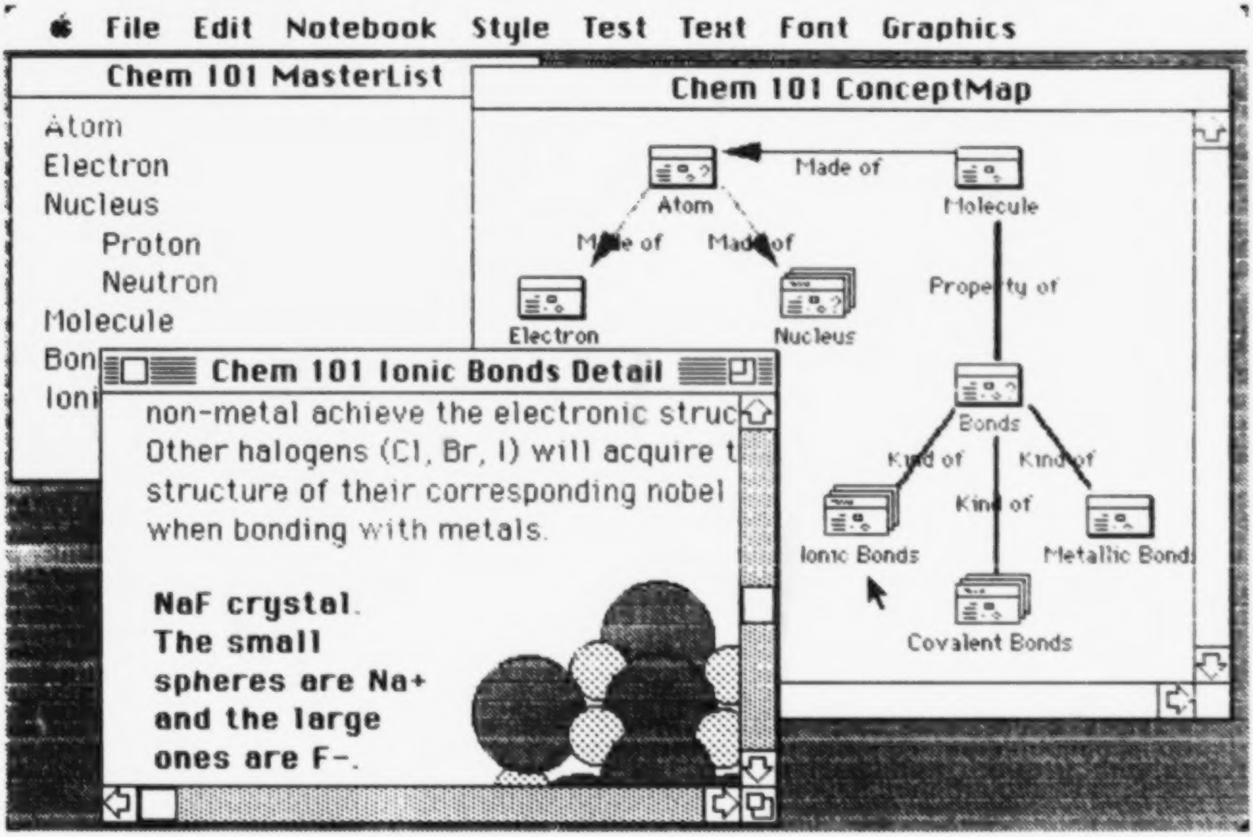
Finally, tools may be designed to facilitate the "job" of learning by including those functions specific to a learning task. Such tools for learning may include utilities that students can use to set goals, build relationships between previous knowledge and new knowledge, test themselves, monitor progress, and so on. For example, Learning Tool (Kozma & Van Roekel, 1986) is a general purpose package that allows learners to enter key ideas and organize them textually into an outline or spatially into a concept map (see Figure 8). This type of tool may facilitate the learning of some specific declarative knowledge, for example the structure of molecules and atoms, and may also serve as an internalized, general model of knowledge organization apart from its use. Another tool, *Stella* (Richmond, 1985) allows learners to build dynamic, procedural systems (see Figure 9). Again, this program may facilitate the learning of some specific procedural knowledge, such as the influence of birth rate on population growth, but it may also serve as a model for the construction of the dynamic relationships of procedural tasks.

Learners

Cognitive tools are still a recent phenomenon and little research has been done on them. But, it is not likely that cognitive tools will facilitate learning for everyone. The more unstructured or unguided a tool is, the more self-regulated learners will need to be and the more skills and abilities they will need to bring to the situation. Students who are deficient in intellectual skills, meta-cognitive strategies, or motivation may find it very difficult to work with these. More structured or guided tools may be useful in situations where a student is given much latitude in a specific production but also needs some support, in particular, support of intellectual or meta-cognitive skills.

Tasks

Computer tools have been used for a wide range of tasks, from creating written or musical compositions to analyzing data. By definition, tools are appropriate for open-ended, higher-order tasks, although the specific component of the task that the tool off-loads may be lower-order (i.e., recalling facts from a data base). Thus, tools are potentially helpful in a broad range of tasks commonly encountered in higher education, from writing a composition to building sophisticated quantitative models in natural or social science. Furthermore, because of the practical utility of these packages, they have been integrated into professional practice. Thus, their use is an appropriate part of the curriculum in schools of engineering, business, education, and so on.



non-metal achieve the electronic struc
Other halogens (Cl, Br, I) will acquire t
structure of their corresponding nobel
when bonding with metals.

NaF crystal. The small spheres are Na+ and the large ones are F-.

Figure 8. An example of a cognitive tool to help learn declarative knowledge (in this case, chemistry), entitled *Learning Tool.*

Graphics

As mentioned above, the computer excels in the range of symbol systems it can employ and, more importantly, process. Some of these symbol systems are auditory but most are visual or graphic. There are three aspects of the graphic component of a software package that may be of concern to designers and researchers.

One is the layout of the screen presentation (Heines, 1984). This deals with the positioning and spacing of text, the use of text support graphics (such as the use of color, boxes, blinking, and underlining), the assignment of consistent functional areas of the screen (such as menus and work spaces), and the use of other graphic conventions (such as icons and windows). The primary role of the type of graphic design is to reduce the cognitive overhead in system operation. Thus, this aspect of the graphics component is more appropriately discussed in the section on user interface.

The second aspect of the graphic component relates to the nature of the task, more specifically the salient visual features of the stimulus of certain tasks. In this regard, the representational symbol systems available with computers can be employed to present appropriate visual stimuli to the learner. This may be particularly useful for learners who do not have significant experience with the phenomenon, especially visual experience. The graphic presentation may provide such learners with important information that does not currently reside in memory. For example, in Figure 10, the program *Surgeon* (Thant & Chung, 1986) is an exploratory environment that attempts to show the user the various layers of tissue and organs as an aortic aneurysm is performed. Learners that have previous experience may find a verbal description sufficient, as they can draw on

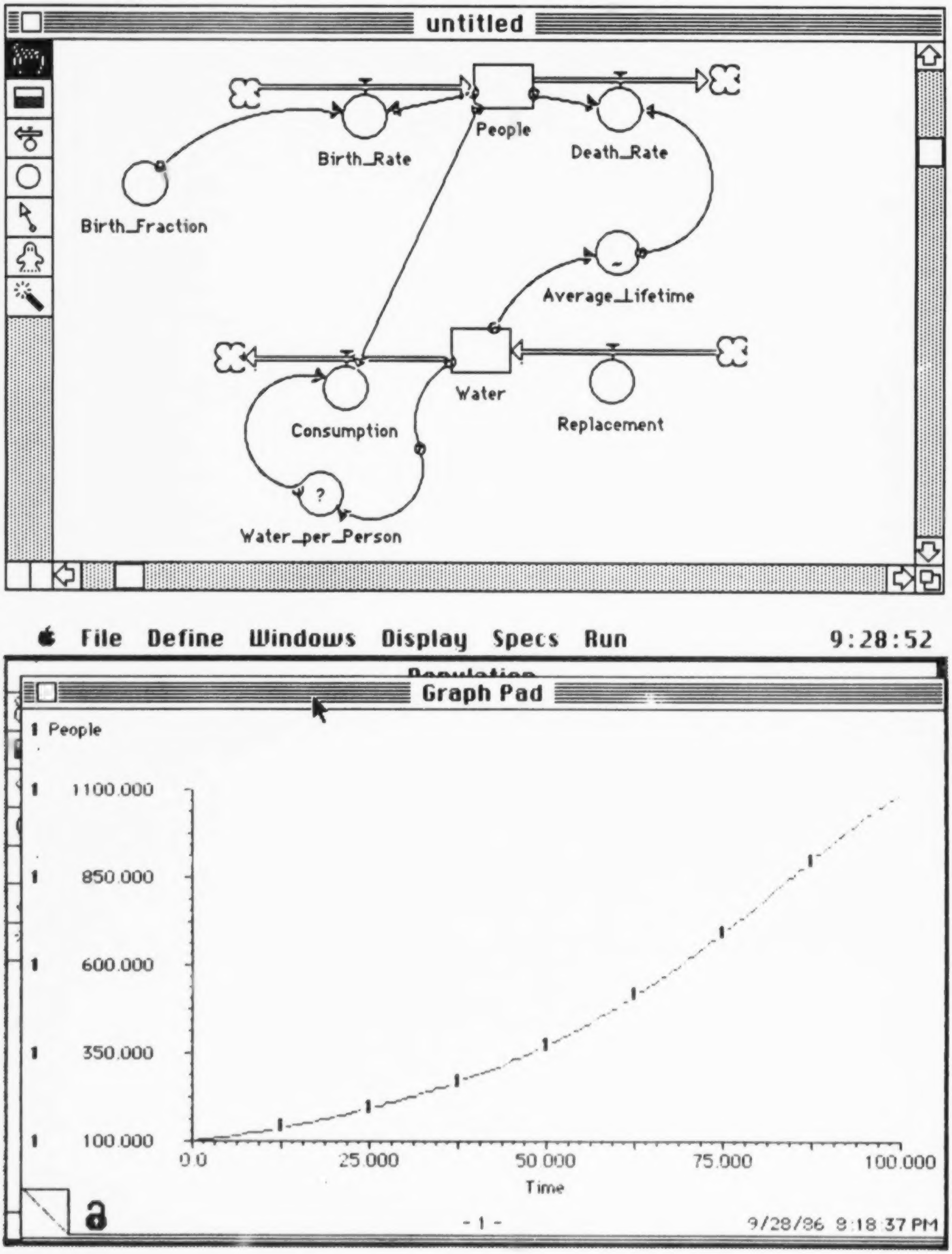
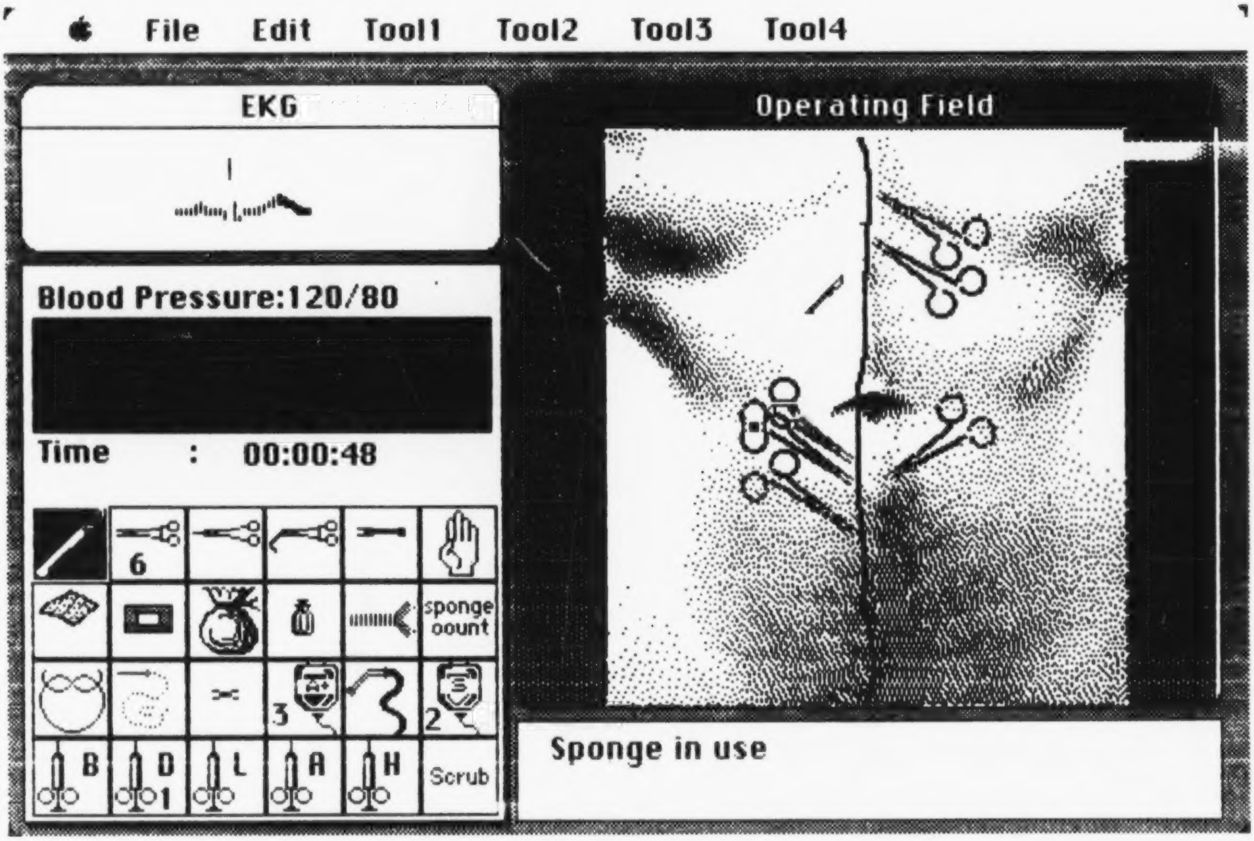


Figure 9. An example of a cognitive tool to help learn procedural knowledge (in this case, population dynamics), entitled *Stella*.



Blood Pressure:120/80

Time : 00:00:48

Sponge in use

Figure 10. An example of the visual representation of stimuli in the program entitled *Surgeon.*

their experience to generate images as necessary to perform the task (Pressley, 1977). In any case, there is some evidence that the presentation of information in both representational and linguistic symbol systems (pictures and text) may in itself increase retention due to dual coding (Levie & Lentz, 1982). Another issue to be explored is the effect of using graphics to represent more abstract phenomena that lack salient visual features, such as the use of animated "ball and stick" models to represent the interaction of molecules.

Perhaps the most significant role the computer can play is to assist learners in making transformations between various symbol systems. Kyllonen, Lohman, and Snow (1984) found that students who score high on tests of visual ability but low on tests of verbal ability, as well as those who score low on visual and high on verbal ability, benefit most on a visual task from training that involves the verbal analysis of visual stimuli (i.e., the transformation of visual to verbal symbol systems). Because the computer is so adept at symbol system processing, software may aid learning by explicitly transforming information in one system to corresponding information in another. An example of this would be the animated bouncing off the floor of a billiard ball, with the simultaneous display of a graph of the force and acceleration over time, and the display of a table generating numbers showing the same relationship. Another example uses *MacSpin* (Donoho, Donoho, & Gasko, 1985) to show a scatter plot in a correlational study examining the depth of earthquakes at various longitudes and latitudes. With this program, the learner can use the cursor to select a specific data point on the plot and call up the record to examine the numerical values for the variables under study (see Figure 11). The learner can also rotate the plot around any of the axes to examine the data from various perspectives.

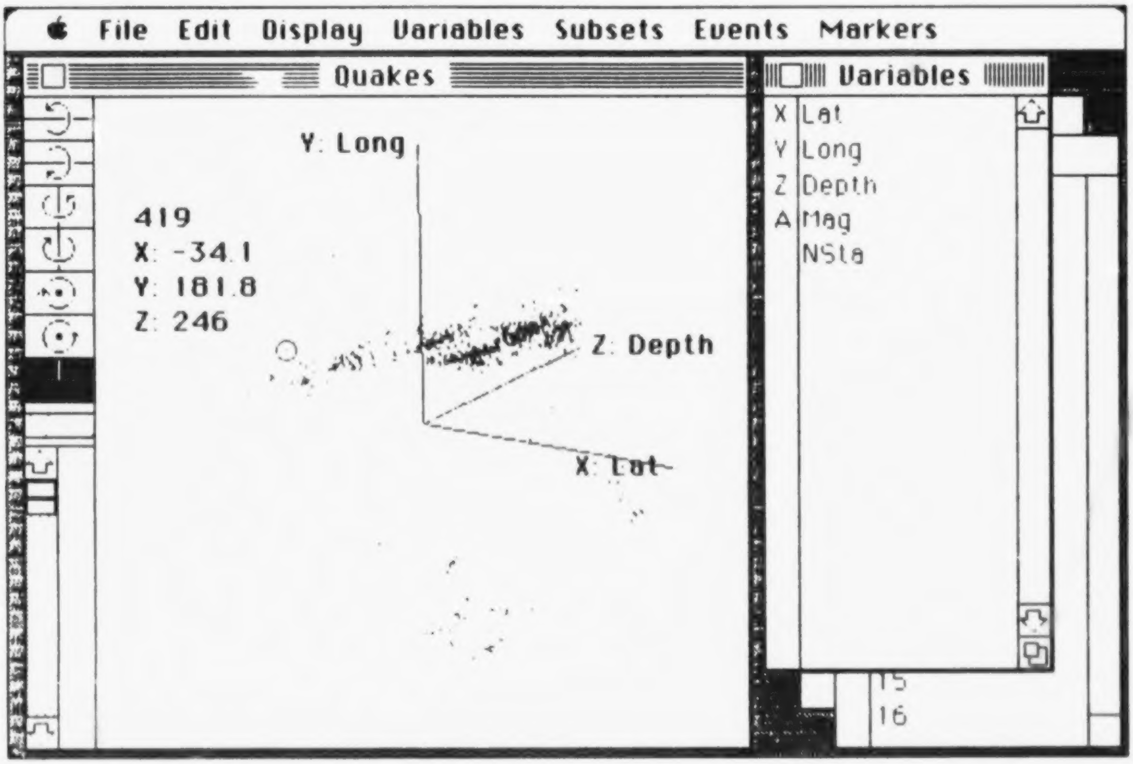


Figure 11. An example of symbol system transformation using the program *MacSpin*.

Motivation

The computer has great potential to provide a highly motivational environment in which to learn and can help to produce a lifelong love of learning. Perhaps the single most important motivational capability of the computer is that it can require the student to participate in instruction and it can allow the learner to control the instruction. The kind and degree of control will be determined by the particular software that is used, but the control capabilities of the computer define its motivational potential.

We discussed in other sections how learner control of computer functions can be motivating. Control over aspects of the instruction can increase a student's sense of his or her own competency and encourage initiative and inquiry. There are some pitfalls in allowing learner control. Some learners may not be sufficiently skilled or motivated to take initiative or may be motivated to avoid particular parts of instruction that the teacher regards as essential. Research has also made it clear that students are often not the best judge of appropriate instructional methods. Snow (1980b) and Clark (1982) found that high ability students tend to choose directive instruction while low ability students tend to choose less structured instruction, in spite of the fact that each type of student may be better suited for the other instructional method. Some safeguards must be built into programs to either become more directive when the student is having difficulty making choices or alert the teacher to a potential problem.

A second problem can arise from giving students control over instruction. Students can become overwhelmed with the number of options available. If the computer interface is not user-friendly, larger numbers of options can actually result in a frustrating experience of confusion and cognitive overload. Perhaps students should be permitted some control over the degree of challenge they face both in the instructional content and in the way the content is presented. But again students must be educated and encouraged to choose an optimally challenging presentation, not one that is so easy that nothing new is learned nor so hard that the student is overwhelmed.

Given these various difficulties associated with learner control of instruction, why is this a positive feature of computer-based instruction? Educators do not simply want to impart a body of knowledge on students. They wish to provide an enduring store of information on which learners will be motivated to build during their lives. Research has shown that learning will last and students will desire to learn more if they are allowed to learn in a personally meaningful way. Highly structured education with clearly defined, externally determined contingencies for learner activities does not encourage nor, in some cases, does not allow the creation of personally meaningful goals in education. Personally meaningful instruction is most possible when learners have some control over their instruction.

The interactivity of computers also equips them to guide individualized learning. Students taught by CBI are not passive learners, but must actively respond to questions, tasks, and challenges presented by the computer. Good programs produce good interactive systems which provide performance information and sometimes evaluations to students while they learn. Furthermore, this feedback can be quite specific, giving explanations for why some learner responses are right or wrong, and perhaps even giving an analysis of errors and directing the student to remediation. An added advantage of interaction with computers is that students can learn in an environment that is relatively free of the pressures and embarrassment that can be associated with learning from a human tutor.

Lepper and Malone (1987) have suggested that the stimulation of curiosity is an important motivational feature of instruction. They distinguish between sensory and cognitive curiosity. The possibilities for using the computer to stimulate curiosity are very great. The computer is still a novelty for many people and, because computer hardware is still changing so rapidly, it is likely to remain a novelty for some time to come. Even when hardware features are held constant, software design is unlimited in its variety and the computer can communicate many auditory and visual symbol systems. In short, the computer is well suited to the stimulation of sensory curiosity.

To stimulate cognitive curiosity, the instruction must point out the contradictions, incompleteness, or lack of parsimony in a learner's knowledge structure or processing. By allowing students to explore large databases, providing specific performance feedback, and giving analyses of errors and error patterns, computers can elicit curiosity from learners. Furthermore, computers can present models of analytical skills for students to observe and emulate.

In short, computers can present intrinsically motivating instruction. Csikszentmihalyi (1978) lists several criteria for intrinsic motivation. First among these is that the task must be personally meaningful. Furthermore, Csikszentmihalyi argues that the performer must be free to establish his or her own level of challenge in a task. The task must be definable and there should be performance feedback available as the task is progressing. By requiring learner participation and permitting learner control and by stimulating curiosity in an interactive environment, computer-based instruction is well-suited to fostering a love of learning.

User Interface

The computer interface is the aspects of the computer or program required for its operation or that provide for interaction with the learner. They include the keyboard or other control devices, the command structure, and the way information appears on the screen.

"User friendly" interfaces take into account the cognitive and motivational processes of the learner. The goal in the design of such an interface is to minimize the conceptual load of the operation of the software, thus reserving as much of the learner's cognitive resources for the learning task. In general, this is done by designing a parsimonious interface (one with only as many functions as needed), and an efficient interface (one with few cognitive requirements per system function), and by creating a system model, or "myth" such as a desk-top metaphor, which draws on an existing cognitive model of the user. Figure 12 shows this implementation on the Apple Macintosh computer.

The cognitive load of operating the program can be reduced by providing menus, thus eliminating the requirement to memorize a command vocabulary and syntax. An interface may provide objects, such as icons representing files or applications, to allow for their direct manipulation by using a touch screen, light pen, or mouse. Finally, more advanced interfaces are coming to allow for natural language control that requires no special knowledge for its operation.

The friendliness of the interface also has motivational aspects. Difficulty in operating the system may frustrate a learner and evoke negative attributions toward the instruction, the computer, or the learner's facility with computers, thus reducing motivation to engage in learning. However, an overly engaging interface might interfere with the primary learning task by distracting the learner. A good trade off would be a non-obtrusive interface, one that is simple and powerful but minimizes engagement.in the operation of the system. An ideal situation might be to create a "myth" that also supports or parallels a cognitive model appropriate to the learning task. The endogenous features of the interface would necessarily engage the learner in the learning task.

Feedback

Feedback has always been considered a crucial part of learning. Theorists suggest that feedback plays at least three important functions in instruction. Feedback can reinforce, inform, and motivate.

Those in the behavioristic tradition have understood feedback as a reinforcer. That is, the presence of feedback after a student's response increases the likelihood that the response will be repeated. The presentation of feedback reinforces stimulus-response associations of interest to the teacher (Skinner, 1968).

The cognitive perspective argues that feedback's effects do more than merely strengthen stimulus-response connections. Feedback, or knowledge of results, "confirms appropriate meanings and associations, corrects errors, clarifies misconceptions, and indicates the relative adequacy with which different portions of the learning task have been mastered (Ausubel, 1968, p. 316)." According to the cognitive view, feedback facilitates learning by providing information.

Finally, feedback can motivate students by encouraging them when they are correct and by challenging them when they make a mistakes. Even in complex situations where responses are not simply right or wrong, students find instructional tasks more stimulating when they can measure their performance against standards of their own making. In order to evaluate their own activity, students need information about their performance (Csikszentmihalyi, 1978).

"Feedback" is actually a very generalized concept that can refer to many different types of instructional events, each of which are more or less appropriate to different instructional methods and which may prove to have different kinds of effects on learners. In its broadest definition, feedback is the discrete event that occurs after a student's action. An important exception to this definition is the occurrence of automatic, covert branching where the student is sent to remedial exercises but may not even know that a special sequence has begun or that the initiation of the sequence was a consequence of his or her action. Feedback should at least be perceptually detectable by the student and have some meaning for the learner.

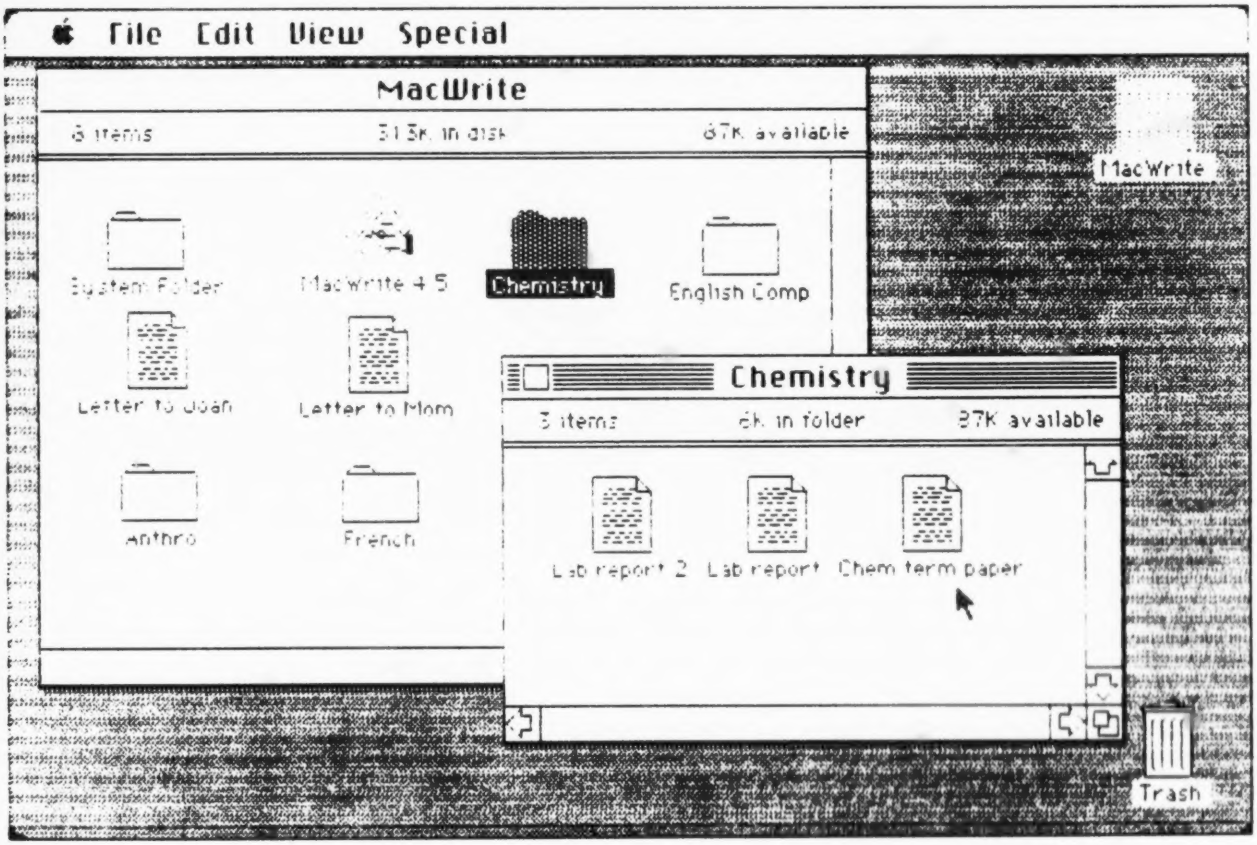


Figure 12. An example of a user interface with low cognitive demands, the Apple Macintosh.

It may be useful to categorize feedback into three types: corrective or directive feedback, informative feedback, and consequential feedback. Corrective feedback is most appropriate where student selections can be regarded as right or wrong and where instructional directedness is desirable. This kind of feedback is therefore most suitable for short-circuiting instruction, such as tutorials. Some examples of corrective feedback are:

1. Notification of correctness. Students are told when their answers are right or wrong.
2. Answer until correct. Students are required to repeatedly try to answer a question until they are correct. After an unsuccessful attempt to answer correctly, students may be told why their choice was wrong and be given hints about the correct answer.
3. Correct answer. Students are told the correct answer to the question.

Informative feedback is useful in situations where student responses are expected to be more complex, where answers may have different degrees of correctness, and where students are encouraged to take greater responsibility for their own instruction. In informative feedback, students are supplied with information about their selection and are left to make self-instructional decisions on the basis of the information. Such feedback is best suited for modeling instruction, though it could appear in complex tutorials or in some activating programs. Some examples of informative feedback are:

1. Advisement. The program may recommend future courses of action to the student on the basis of the student's progress or the student's particular responses to particular situations.

2. Elaboration. Students' responses are followed by extended discussions of why a response may or may not be the best selection and, in sophisticated programs, may supply students with information about any pattern of errors that is emerging from their responses.

3. Paradigm. Students are given an example of a typical or good answer and expected to compare their answers to the model.

Consequential feedback is most appropriate for activating instruction because it puts the greatest cognitive burden on the learner. It gives no explicit direction to the student but provides explicit or nonspecific information which the student can use to make further self-instructional decisions. The only requirement is that consequential feedback follow a learner action and that it be perceptually detectable by the student.

Research on feedback effects has had a long history. In 1932, for example, Trowbridge and Carson (1932) gave blindfolded subjects 100 trials in drawing lines exactly 3 inches long. Subjects who were told when they made good approximations of 3-inch lines showed much improvement over 100 trials while those who received no information about their performance showed no improvement.

However, the research on feedback has not produced a unanimous verdict. Most of the research on feedback in media has been on corrective feedback, typically the presentation of the correct answer. For example, when reviewers examined the record of feedback effects in programmed instruction, they were surprised to find that in many instances the presentation of the correct answer during instruction seemed to inhibit learning (e.g., Anderson & Faust, 1973; Kulhavy, 1977). In a recent meta-analysis, Schimmel (1983) found that feedback had higher effects when used in computer-based instruction than when used in programmed instruction. What would explain these findings?

Kulhavy (1977) defined the construct "presearch availability" to explain the poor performance of feedback in some situations. According to Kulhavy, if the correct answer is available to students before they compose their responses to questions, students will copy the answers. Presearch availability will inhibit learning because students will attend less to instruction and not practice the cognitive processes necessary to compose their own responses.

Bangert-Drowns, Kulik, and Kulik (1985) confirmed that feedback effects are strongly mediated by presearch availability. They conducted a meta-analysis on the feedback effects in programmed and computer-based instruction. The meta-analysis clearly showed that feedback effects were higher (0.38 standard deviations) when correct answers were given only after the student generated a response. When correct answers were available prior to the creation of an answer, the average effect size for feedback was negative (-0.13 standard deviations).

This construct can explain why feedback is often more effective in computer-based instruction than in programmed instruction. Most computer-based instruction programs control for presearch availability, presenting correct answers only after students respond to questions. In programmed instruction, answers may be available to students on the same page as the questions. Programmed instruction, especially when it is in a book format, is usually not as carefully controlled for presearch availability. This is perhaps the most important statement that can be made about feedback, that it must be made contingent on the response of the learner.

9. Research Agenda

Narrowing the focus of our research on technology in higher education to the educational application of computers would at first seem to be a manageable task. However, those proposing the agenda for research on educational computing contend otherwise (Sheingold, Kane, & Endreweit, 1983; Salomon, 1984; Salomon & Gardner, 1986). Research issues within this domain range broadly, and include:

- the impact of computing on educational institutions
- the impact of computing on curriculum
- differential access to computers and types of software for different socio-economic groups or genders
- the impact of computing on the roles of teachers and students
- skills needed by instructors to effectively implement computers in their courses
- learners' attitudes and perceptions of computers and their use
- the impact of the unique capabilities of computers on what is learned by students
- the transfer of what is learned in computer environments to non-computer contexts
- the effects of computers on the way students think and learn.

A particularly urgent need expressed by Salomon (1984; Salomon & Gardner, 1986) is the study of the long-range, cumulative effects of computer use before it is so pervasive that, as in the case of television, there is no chance for an appropriate control situation.

All of these topics are important and potentially fall within the research mission of the Program on Learning, Teaching, and Technology at NCRIPTAL. But limited resources warrant a more circumscribed agenda. While we plan some research examining the computer's impact on the structure of colleges, the organization of the curriculum, and the role of the faculty, it will be woven into the agenda of other NCRIPTAL programs. The primary focus of our program will be to study the impact of the more unique capabilities of computers on the cognition and motivation of students. Within the various types and components of software designs that we have described, we will focus on the following questions based on the hypotheses embedded in our discussion:

Guided Simulations and Exploratory Environments

- Do less able students benefit more from the additional assistance provided by a guided simulation?
- Are these students hurt in exploratory environments?
- Do more able students benefit from the open-endedness of exploratory environments?
- Are these students inhibited by the structure of a guided simulation?

We will limit our examination to the use of these simulations on procedural tasks in natural and social science courses.

Cognitive Tools

- Do tools improve learning and performance or do they merely alter them?
- What are the patterns of their use?
- What do learners do with the additional cognitive resources provided by tools?
- Do learners internalize the processes performed by tools, and if so, under what conditions?
- Which learners benefit most from tools?

We will limit our research to tools designed for two types of tasks, those designed to assist with written composition, and those designed specifically to aid metacognitive learning tasks.

Graphics

- Does aiding the learner in transforming information into different symbol systems facilitate learning?
- Do learners of high or low spatial ability benefit most?

Motivation

- How do motivational embellishments interact with learner aptitudes to affect learning?

Feedback

- What cognitive functions are served by the various types of feedback?
- Which are better for different tasks and learners?

Methodological Concerns

Salomon and Gardner (1986) make several important points in discussing methodological issues in computer research. While acknowledging the importance of experimental analysis, they propose that it be preceded by more exploratory, open-ended observations in which anecdotal and ethnographic methods are employed. In such a design, all events are allowed to happen on their own in all their complexity, and the research is sensitive to process and context as well as product or outcome. This approach is particularly important for a new area of study where variables, relationships, and mechanisms are still emerging. In this regard, Salomon and Gardner also recommend that a variety of outcomes be measured and examined, and that the researcher be sensitive to a range of effects, both anticipated and unanticipated.

Our research on the issues identified above will progress in two phases over the next four years. In the first phase we will conduct observational research with small groups and individuals using software with the features specified by our research questions. We will collect a variety of aptitude and outcome data, including think-aloud protocols, measures of prior knowledge, learning strategies, attitude, and anxiety (McKeachie et al., 1986). Given the lack of useful constructs to describe moderating situational variables, we will be particularly sensitive to collecting and organizing information on these, as well. Our intent, with the completion of the first phase, is to refine our hypotheses relating software features, learners, and tasks. We will also construct a taxonomy of situational variables and profiles that moderate computer applications to influence learning.

The second phase will involve a series of controlled experiments which test these refined hypotheses. Alternative versions of software will be specially designed in collaboration with software developers. Several classes at participating colleges will receive one version or the other, and appropriate aptitude and outcome measures will be taken. Multiple regression analyses will examine main and interaction effects to test the hypotheses.

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